NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COMPARISON OF MECHANICAL PROPERTIES OF FLAT SHEETS, MOLDED SHAPES, AND POSTFORMED SHAPES OF COTTON-FABRIC PHENOLIC LAMINATES

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SUMMARY

Tests were conducted to determine the properties of (a) several untreated commercial cotton-fabric phenolic sheet laminates, (b) the same laminates after exposure to a typical postforming heating cycle, (c) industrially postformed shapes made from one of these materials, (d) industrially molded and laboratory-molded shapes, and (e) flat panels postformed in the laboratory from the laboratory-molded shapes. Tensile properties, flexural properties, and water absorption were determined.

In general, the tensile strength of the sheet laminates varied from 8,000 to 12,000 psi, the tensile secant modulus varied from 0.8×10^6 to 1.3×10^6 psi for the stress range 0 to 2,500 psi, the flexure strength varied from 15,000 to 26,000 psi, and the flexure modulus varied from 0.7×10^6 to 1.2×10^6 psi. Most of the materials showed directional variations in strength when tested parallel to, perpendicular to, and at 45° to the warp yarn in the face ply of the fabric. In general, the lowest strength values were obtained in the 45° direction. There was some indication that for those materials in which the tensile strength and modulus were greater in one direction, the flexural strength and modulus were also greater in that direction.

In general, heating the laminate sheets in oil at 375° F up to 120 seconds or in air at 400° F up to 5 minutes, as was done in the postforming operation, resulted in slight changes in dimensions. The thickness increased as much as 3.5 percent and the length and width decreased as much as 1 percent with one exception, in which case the thickness increased 14 percent. The flexural strength decreased less than 12 percent in most cases.

Industrial postforming decreased the strength of the flat sections of the postformed parts less than 15 percent in most cases.

The water absorption did not change appreciably for the flat sections, but increased approximately 20 percent for a 30° curved section and approximately 50 percent for a 90° curved section.

The strength of industrially molded parts was significantly less than that of similar sheet laminates. The tensile strength of the flat sections was less by an average of approximately 35 percent and the flexural strength, by an average of approximately 20 percent.

The flexural strength and modulus of the flat sections of laboratory-molded V-panels were equal to or slightly greater than those of similar sheet laminates. In general, postforming did not appreciably affect the strengths of the formerly flat sections of these panels. The results differed for the postformed 45° and 90° curved sections, depending somewhat on the side of the material under tension during test and on the orientation of the warp yarn in the top layer of fabric. In most cases, the flexural strength of these formerly 45° curved sections was equal to, or not more than approximately 40 percent less than, the flexural strength of the flat sections, and the strength of the formerly 90° curved sections was equal to, or not more than approximately 25 percent less than, the strength of the formerly 45° curved sections.

The water absorption for the 45° and 90° curved sections of the laboratory-molded panels was equal to or less than that for the flat sections. After postforming, in general, the absorption was not changed appreciably for the flat sections but was as much as approximately 25 percent higher for the formerly 45° curved sections and as much as approximately 50 percent higher for the formerly 90° curved sections.

INTRODUCTION

The first known literature reference to the fact that cured phenolic laminates can be formed when heated is contained in a footnote to a table in a paper published in 1922 by Dellinger and Preston (ref. 1). They stated that thin sheets could be pressed to simple shapes when warm. However, the art and commercial application of postforming phenolic laminates was developed within the last 15 years. Postforming was developed and used extensively, especially in the construction of aircraft components, during World War II. One of the foremost early workers with this technique, Beach (refs. 2 to 7 and ref. 8 by Nash and Beach), refers to the process as thermoelastic forming of laminates. Types of laminates particularly suited for postforming, methods of postforming, and applications of postforming have been described by various investigators (refs. 9 to 17).

The fact that phenolic laminates can be postformed points out forcefully that thermosetting plastics are to some extent thermoplastic. Fully cured standard grades of phenolic laminates in thin sheets become soft and pliable at elevated temperatures and can be formed into simple shapes. However, forming is easier, more complicated shapes can be made, and improved results are obtained if appropriate modifications are made in the resin and fabric used. The resin may be modified to obtain a wide range of flexibility at the temperature of forming (ref. 8); the use of undercured stocks is not recommended by Beach (see ref. 8). Fabrics that stretch more, without rupturing, than the ducks commonly used in plastic laminates may be used (ref. 18). With a suitably formulated resin the limiting factor in forming is the amount the fabric can be stretched (ref. 8).

This report presents data on the properties of (a) several commercial postforming cotton-fabric phenolic laminates, (b) industrially postformed shapes made from one of these materials, (c) industrially molded shapes made from a similar base fabric and resin, and (d) laboratory postforming stock, molded shapes, and postformed shapes made from the same lot of resin-coated fabric used by one of the manufacturers to make one of their commercial postforming stocks.

This investigation was conducted under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics. The cooperation of the Continental-Diamond Fibre Co., the Formica Co., North American Aviation, Inc., the Richardson Co., the Synthane Corp., and the Westinghouse Electric Corp. in supplying materials for use in this investigation is greatly appreciated. The assistance of Mesdames R. H. Thomason, R. E. Mann, and M. Jorgensen in conducting the tests and of Mr. John Mandel in advising in the statistical analysis of the data is gratefully acknowledged.

MATERIALS

The materials used in this investigation are listed in table I. The same stock of resin-impregnated fabric was used in samples SB2, SC1, SC2, MC1, and PC1 (code explained in the footnote, table I). Likewise, samples SB3, SC3, MC2, and PC2 were prepared from a single stock of resin-impregnated fabric.

The following data were supplied concerning materials furnished by source B. The materials were molded in a hydraulic press with steam-heated platens. The molding temperature was measured by a thermocouple placed in a cushion one-twentieth of the distance between the laminate and the press platen. Sheets SB2 and SB3 were molded at 1,100 psi. Sheet SB2 was held in the press for 15 to 30 minutes after reaching 160° C.

Sheet SB3 was held in the press for 30 minutes after reaching 153° to 155° C. Angles MB1 and channels MB2 were molded at 2,000 psi for 30 minutes after the molding temperature of 160° C was reached. The platens were cooled rapidly by circulating cold water. The outer faces of samples MB1 and MB2 were machined to the indicated dimensions.

The samples made at the National Bureau of Standards were molded in a hydraulic press with steam-heated platens. In the 4-ply samples, the warp yarns of the two center plies were parallel to each other and perpendicular to the outer plies, resulting in the outer plies being parallel to one another. In the 9-ply samples, the warp yarns of the two outer plies were parallel to one another; adjacent plies were perpendicular to one another throughout the panel. In the 16-ply samples, the warp yarns of the two outer plies were parallel to one another; adjacent plies were perpendicular to one another except for the two center plies which were parallel to one another. The temperature during molding was measured with a thermocouple placed between plies of the sheets. The layers of resin-impregnated fabric were placed in the press and the temperature was raised to 153° to 155° C in 15 minutes and maintained there for 30 minutes. The platens were cooled rapidly by circulating cold water.

The pressures used for molding the various samples at the National Bureau of Standards were as follows:

Sample	Pressure, psi
Sheets SC1	200
Sheets SC2	1,000
Sheets SC3	500
Molded V-panels MC1	1,000
Molded V-panels MC2	1,000

Sample SC3 was molded so as to obtain a laminate duplicating sample SB3, which was made with a molding pressure of 1,100 psi. However, a pressure of 1,000 psi caused an excess of resin to run from sample SC3. The duplication was therefore attempted on the basis of density and it was found that a pressure of 500 psi produced a laminate with a density similar to that of the SB3 sample material.

The V-sections, samples MC1 and MC2 illustrated in figure 1, were molded in 1/16-inch thickness from four plies of resin-impregnated fabric by using a steel mold. Three types were made, varying in the orientation of the warp yarn of the outer plies with respect to the lengthwise direction of the molded V-section; the R designation (table I) indicates parallel orientation, the S designation, 45° orientation, and the T designation, perpendicular orientation. After laminating, the edges were trimmed and the panels were stored at 25° C and 50-percent relative humidity for at least 96 hours before postforming. Some of these samples were postformed into essentially flat sheets, samples PC1 and PC2.

POSTFORMING

Samples MC1 and MC2, molded V-panels, were postformed into essentially flat sheets by heating in a circulating-air oven, removing, and pressing between hardwood blocks in an arbor press for 30 seconds. The pressure was applied less than 5 seconds after removal from the oven. The temperatures and times used were slightly below those that would produce blistering as determined by trial experiments. Sample MC1 was heated for 180 seconds at 204.5° C (400° F) and sample MC2 for 60 seconds at this same temperature. The resulting flat panels, samples PC1 and PC2, made from the V-sections had slight ridges along the former lines of curvature. The deviation from flatness of these ridges was less than 0.010 inch in most cases.

The PG1 channels and PG2 angles were postformed from sample SB1 by heating in a circulating-air oven at $274^\circ \pm 14^\circ$ C ($525^\circ \pm 25^\circ$ F) for 55 to 60 seconds and molding between hardwood blocks. The postformed parts, samples PG1 and PG2, and their respective blanks, cut from sample SB1, are shown in figures 2 and 3, respectively.

HEAT TREATMENTS

The effects of the heating conditions used in postforming were determined by heating specimens of samples SA1, SA2, SB1, SD1, SE1, SF1, and SF2 by two different methods. In one method the materials were placed in a circulating-air oven at 204.5° C (400° F) for the period of time indicated in tables II and III. In the other method the materials were immersed in oil at 190.5° C (375° F) for the period of time indicated in tables II and IV. In some of the latter tests, SAE 20 lubricating oil containing 10 percent sulfur was used; in other cases, Markol paraffin oil was used. The longest period of time used was slightly less than that required to produce blistering of the material.

SAMPLING PROCEDURE

The specimens for all tests of samples SA1, SA2, SD1, SF1, and SF2 were cut from a single sheet of each material. Since sample SB1 consisted of blanks cut for forming, the largest about 8 by 9 inches, as shown in figures 2 and 3, groups of specimens for a test were composites taken from three of these nominally identical blanks. The tensile test specimens of sample SE1 were taken from one sheet and the flexural test specimens from another. Large pieces of these samples were subjected to the heat treatments before being cut into test specimens.

The specimens for all the tests of samples SB2-8X, SB2-4X, SB3-8Y, and SB3-4Y were also cut from a single sheet of each material. For samples SB2-16X and SB3-16Y, the sheets were cut into halves, one-half of each sheet was then cut in half, and sets of specimens were taken from each of these three parts.

Sets of test specimens were cut from samples SA1, SA2, SB1, SB2, SB3, SD1, SE1, SF1, and SF2 in each of three directions. The lengths of the test specimens were either parallel to, perpendicular to, or at 45° to the warp yarn in the fabric of the face ply.

Five tensile specimens in the parallel direction only and five flexural specimens in each of the three directions were cut from each sheet of samples SC1, SC2, and SC3 as illustrated in figure 4. One sheet each of SC1 and SC2 and two sheets of SC3 were tested.

Four flexural and two tensile specimens were cut from each of the three sides of two samples of channels MB2-16, MB2-8, and MB2-4. Six flexural and two tensile specimens were cut from each of the two sides of two pieces of angles MB1-16, MB1-8, and MB1-4. The specimens were cut from samples MB1 and MB2 so that the lengthwise dimension was parallel to the length of the channels and angles. The orientation of these specimens is illustrated in figure 5.

Six flexural specimens were cut from each panel of samples PC1 and PC2 so that the lengthwise direction of the specimens was perpendicular to the axis of the V-section originally molded in the sheets. Since the flattened V-sections had slight ridges at the site of the former curvatures, the flexural specimens had three ridges across each one. Drawings of the V-sections before and after postforming are shown in figure 6. The figure shows that the two outer ridges were obtained by flattening 45° bends and the inner ridge by flattening a 90° bend.

Water-absorption specimens, 0.5 by 1.5 inches, were cut from strips, 1.5 inches wide, of samples MC1, MC2, PC1, and PC2 so that three types were produced. One type was cut from a flat section outside the V-area.

A second type was cut with a 45° bend or a ridge resulting from a flattened 45° bend along the longitudinal center line. The third type was cut with a 90° bend or a ridge resulting from a flattened 90° bend along the longitudinal center line. For these measurements, panels of samples MC1 and MC2 were cut crosswise to the longitudinal axis of the V-section into two pieces; one piece was cut into test specimens, and the other piece was postformed flat, giving panels of PC1 and PC2, and then cut into test specimens. Consequently, test specimens both before and after postforming were cut from the same panels.

Water-absorption specimens, 0.5 by 1 inch, were cut from PG1 channels and PG2 angles with the axis of the curved section parallel to the 1-inch dimension.

METHODS OF TEST

Tensile Tests

The tensile properties were measured in accordance with Method No. 1011 of Federal Specification L-P-406a (ref. 19) except that the rate of head separation was maintained at 0.05 inch per minute throughout the test. Load-extension curves were obtained on a Southwark-Templin autographic recorder which was operated by a Southwark-Peters plastics extensometer mounted on the specimens. The tests were made on a universal hydraulic testing machine using ranges of 0 to 240 pounds, 0 to 1,200 pounds, or 0 to 2,400 pounds. The test specimens conformed to type 1 of Method No. 1011.

Flexure Tests

The flexural strength and modulus of elasticity in bending (flexural modulus) were measured in accordance with Method No. 1031 of Federal Specification L-P-406a (ref. 19) using the 0- to 240-pound range of a universal hydraulic testing machine. The tests were conducted at a span-depth ratio of 16:1 using the equipment described in reference 20 and pictured in reference 21. The load-deflection curves were obtained on a Southwark-Templin autographic recorder which was operated by a Southwark-Peters plastics extensometer. The supports and loading nose of the jig were rounded to a radius of 1/32 inch. The test specimens were 0.5 inch wide and 5 inches long.

Water-Absorption Tests

The water-absorption tests were made in accordance with Method No. 7031 of Federal Specification L-P-406a (ref. 19), except that it was found necessary to reduce the size of the specimens. The specimens of samples SB1, PG1, and PG2 were 0.5 by 1 inch. The specimens of samples MC1, MC2, PC1, and PC2 were 0.5 by 1.5 inches.

Conditioning

All specimens were conditioned at least 48 hours at 25° C and 50-percent relative humidity prior to testing and were tested at the same conditions.

Statistical Calculations

The variability of experimental results, which includes both test error and variability among different specimens of the same material, is expressed in most cases in terms of the coefficient of variation C.V. calculated by the following formula (ref. 22):

$$\text{C.V.} = \frac{\sqrt{\sum (d_i)^2/(n - 1)}}{A} \times 100$$

where

A average result

C.V. coefficient of variation, percent

d_i deviation of individual result i from average

n number of test results

The standard error of the average was calculated according to the formula

$$\text{S.E.} = \sqrt{\sum (d_i)^2/n(n - 1)}$$

The results obtained were analyzed statistically to determine whether observed differences were significant.

RESULTS

Initial Properties of Sheet Materials

The tensile strength, tensile modulus of elasticity, and strain at failure of cotton-fabric phenolic sheet laminates are presented in tables V, VI, and VII, respectively. The flexural strength and flexural modulus of elasticity are presented in tables VIII and IX, respectively.

The average tensile strengths of the flat sheets in all directions were in the range of 8,000 to 12,000 psi, except for the samples SF1 and SF2 which were higher in the lengthwise direction (table V). Some of the materials did not show any appreciable directional variation in tensile strength; in some materials, the tensile strength in the 45° direction was as much as approximately 25 percent less than that in the lengthwise and crosswise directions, and, in others, the tensile strength in both the 45° and the crosswise directions was less than that in the lengthwise direction. For the SF1 and SF2 materials, the tensile strengths were approximately 40 to 50 percent less in the 45° and the crosswise directions than in the lengthwise. For some materials, certain thicknesses showed directional variations with respect to tensile strength whereas other thicknesses of the same material did not. There was no consistent indication of variation of tensile strength with the thickness of the laminate for a given sample.

The average values for tensile modulus (table VI) over the stress range of 0 to 2,500 psi ranged from approximately 0.8×10^6 to 1.3×10^6 psi. In most cases, those materials exhibiting higher tensile strengths in one direction also exhibited higher tensile-modulus values in the same direction. The modulus in the 45° and crosswise directions was less than that in the lengthwise direction by as much as approximately 30 percent.

The values for strain at failure (table VII) differed widely for the materials tested, from average values of 1.7 to 7.5 percent. There was no consistent behavior with respect to the direction of warp yarn or to tensile strength or tensile modulus.

The average values obtained for flexural strength (table VIII) varied from approximately 15,000 to 26,000 psi. Directional variations in flexural strength were usually observed in those materials in which variations in tensile strength had been observed. In some cases, there was no significant directional effect for flexural strength; in some cases, the strength was less by as much as approximately 20 percent in the 45° direction only; and, in others, the strength was less in both the 45° and crosswise directions. However, as in the tensile tests, the SF1 and SF2 materials showed high strength values in the lengthwise directions and significantly lower values for the 45° and crosswise directions.

The average values for flexural modulus of elasticity (table IX) ranged from approximately 0.7×10^6 to 1.2×10^6 psi. Again, as in tensile properties, in most cases those materials showing directional variations in flexural strength exhibited directional variations in the flexural modulus. The values obtained for the modulus for the transverse directions were as much as approximately 30 percent lower than those obtained for the lengthwise direction, and, in a few cases, were as much as approximately 10 percent higher.

Properties of Heat-Treated Sheet Materials

The dimensional changes on heating, the effects of heating in air on the flexural properties, and the effects of heating in oil on the flexural properties of the sheeet materials are presented in tables II, III, and IV, respectively.

The actual measurements of the dimensional changes (table II) are significant to 0.2 percent, but observed differences of less than 1 percent are not considered to reflect real differences in the materials. The heating of laminate sheets in oil at 375° F up to 120 seconds resulted in only slight increases in thickness in most cases, varying up to approximately 3 percent, with no significant changes in others. In one material, SF1, the thickness increased approximately 14 percent. In most cases, the decrease in length or width was too small to be statistically significant. However, in view of the consistency of this effect, it is believed that, although small, the decrease caused by heating is real.

Heating the laminate sheets in air at 400° F up to 6 minutes also resulted in only slight increases in the thickness, the highest increase being 3.5 percent. In most cases, there was no significant change in the length or width during the heating cycle, but, as above, the consistency of the small changes would indicate a small but real decrease. Sample SA2-16 warped considerably during both heat treatments.

Heating the sheet laminates in air up to 6 minutes also decreased the flexural strength less than approximately 10 percent (table III). The flexural modulus of elasticity decreased less than approximately 20 percent in most cases.

The immersion of the laminates in the hot oil up to 120 seconds decreased the flexural strength less than 12 percent in most cases. The flexural strength of sample SF1 decreased more when immersed in a Markol paraffin oil than when immersed in the lubricating oil. The effect of varying the composition of the immersing fluid was not studied further. In most cases, the decrease in flexural strength was accompanied by a decrease in flexural modulus of elasticity. In a few isolated tests, however, heating increased the modulus slightly.

Effect of Industrial Postforming on Properties of Flat Sections

Sample SB1-16 was taken from production materials being used to postform ammunition chute parts. The mechanical properties of flat sections cut from two of these postformed parts, samples PG1-16 and PG2-16, were determined and are reported in table X. The water absorption of flat sections cut from sample SB1-16 and of flat and curved sections cut from samples PG1-16 and PG2-16 are also reported in table X.

Postforming resulted in a slight decrease in tensile strength and tensile modulus and a slight increase in strain at failure for sample PG1, which was tested only in the lengthwise direction. The flexural strengths of both postformed samples PG1 and PG2 decreased in all three test directions. The average decrease in flexural strength for the PG1 specimens was approximately 13 percent, whereas the average decrease for the PG2 specimens was only 4 percent. The flexural modulus also decreased in all three directions for the PG1 sample, the average decrease being approximately 10 percent, but did not change significantly for the PG2 sample.

The water absorption did not change appreciably for the flat sections of the postformed parts. The water absorption of the curved sections of both postformed samples was higher than that of the flat sections. The average increase was approximately 50 percent for the PG1 sections and 20 percent for the PG2 sections.

Properties of Molded Angles and Channels

The tensile and flexure properties of specimens cut from both molded channels MB1 and molded angles MB2 are presented in tables XI and XII, respectively. The differences in properties between flat sheet SB2 and angle and channel laminates obtained from the same source and molded from similar materials are shown in table XIII.

Data were not available to permit a comparison of the properties of the molded angles and channels with those of flat sheets made from the same materials. However, a comparison of the average values obtained for the molded pieces with the average values obtained for flat-sheet sample SB2 made from similar materials indicates that the tensile strength for the molded parts is approximately 30 to 40 percent less than that for the flat sheets. The tensile modulus of elasticity is approximately 5 to 25 percent less. The flexural strength and the flexural modulus of elasticity are approximately 10 to 25 percent less for the molded parts than for the flat sheets.

There was no significant difference between the values obtained for the channels and the angles. However, the values obtained for the flexural strength with the molded side in tension were slightly higher than those obtained with the machined side in tension. Also, there was some indication that the tensile strength and tensile modulus of the molded pieces increased slightly with increasing thickness.

Effect of Postforming on Properties of Curved Sections

The molded V-sections, samples MC1 and MC2, were postformed to flat panels. Specimens were cut from the flat and the formerly 45° curved and 90° curved areas. The flexural strength, flexural modulus of elasticity, and water absorption were determined. The results are presented in tables XIV, XV, and XVI, respectively.

In discussing the test results obtained on these panels, two separate meanings are applied to the use of angular degrees. In one case, 0°, 45°, and 90° refer to the direction of the warp yarn in the face ply of the laminate with respect to the lengthwise direction of the molded V. The letters R, S, and T are used in the sample designations to indicate, respectively, these three directions. The angles 45° and 90° also refer to the amount of bending caused by the postforming operation of the molded V's, as shown in figure 6.

In analyzing the results of the effects of postforming, the assumption was made that differences in strength values between the postformed flat sections and the postformed curved sections were due to the postforming operation and not to the original molding operation. In other words, it was assumed that the strength of the curved sections of the original molded V-panels was the same as that of the flat sections. To achieve this condition insofar as possible, extreme care was used in molding the V-panels. Some indication that this assumption was valid is given by the data for water absorption, presented in table XVI. These data show that the water absorption of the curved sections of the V-panels was equal to or less than that of the flat sections of these panels.

The results of the flexural-strength tests for PC1 and PC2 are shown graphically in figures 7 and 8. There was little or no change in the flexural strength of the flat sections of the molded MC1 V-panels on postforming (fig. 7 and table XIV). As in the sheet laminates, the strength of the postformed samples with the 45° warp yarn was slightly less than that with lengthwise and crosswise warp yarn. For the postformed PC1 samples, the flexural strength of the formerly 45° and 90° curved sections averaged approximately 25 percent and 35 percent, respectively, less than that of the flat sections, except for one sample. The sample oriented 45° with respect to the warp yarn, when tested with the loading nose applied on the convex side, had a flexural strength approximately 15 percent higher than that of the flat sections. In general, the specimens of the formerly curved sections had slightly higher strengths when tested on the convex side than when tested on the concave side.

As in the MC1 samples, postforming did not appreciably affect the flexural strength of the flat sections of the MC2 panels (fig. 8). The flexural strengths of the formerly 45° and 90° curved sections, sample PC2, when tested on the convex side, were either equal to or greater than those of the flat sections. However, when the formerly curved sections were tested on the concave side, the flexural strength of the formerly 45° curved sections averaged approximately 20 percent less than that of the corresponding flat sections, and that of the formerly 90° curved sections averaged approximately 35 percent less than that of the flat sections. Thus, in all of the samples of the formerly curved sections, the flexural strength was significantly less when tested with the loading nose applied on the concave side than when tested with it applied on the convex side.

For the flat sections, both before (samples MC1 and MC2) and after (samples PC1 and PC2) postforming, the flexural strength of the MC1 and PC1 panels was approximately the same as that of the corresponding MC2 and PC2 panels in most cases (figs. 7 and 8). For the formerly curved sections, the values for flexural strengths for the two sets of panels were similar when the specimens were tested on the concave side. When they were tested on the convex side, however, the formerly curved sections of the PC2 samples with 0° and 90° warp yarn had higher strength values than did the PC1 samples.

The effect of postforming on flexural modulus of elasticity of curved sections is shown in figures 9(a) and 9(b). As can be seen from table XV, the flexural modulus of elasticity of the flat sections of the postformed PC1 V-panels was approximately 25 percent less than that of the original flat section MC1. For the PC1 panels, the moduli for the formerly 45° and 90° curved sections were approximately 15 and 20 percent less, respectively, than those for the corresponding flat sections, except for the samples oriented 45° with respect to the warp yarn, which were unchanged when tested on the convex side.

For the PC2 panels, in which the orientation of warp yarn was 45° and 90°, there was no significant change in the flexural modulus of the flat sections on postforming, with one exception, in which the flexural modulus for the postformed flat sections was more than that for the original molded flat sections, when the angle of the warp yarn was 0°. When the postformed panels were tested on the convex side, the moduli for the formerly 45° and 90° curved sections were equal to or up to approximately 20 percent greater than the modulus for the corresponding flat section. There was no significant difference between the values obtained for the 45° and the 90° sections tested on the convex side.

When the postformed panels were tested on the concave side, however, the modulus for the formerly 45° curved sections was 5 to 10 percent lower than that for the corresponding flat section, and the values obtained for the formerly 90° curved sections were approximately 10 to 20 percent lower than those obtained for the corresponding flat section.

The flexural modulus of elasticity of the flat sections of the MC1 samples was greater than that of the MC2 samples but, after postforming, the reverse was true for the formerly flat sections and the formerly curved sections.

The results of the water-absorption tests are shown in figures 10 and 11 and table XVI. For the original molded MC1 V-panels, in general, there was no appreciable difference in the water absorption of the flat sections, 45° curved sections, and 90° curved sections (fig. 10(a)). Also, there was no appreciable effect of warp-yarn orientation on water absorption.

Postforming the V-panels did not appreciably affect the water absorption of the flat sections of the PC1 panels. However, the water absorption increased for the formerly 45° and 90° curved sections, the increase being approximately 25 percent for the 45° sections and approximately 50 percent for the 90° sections. Again, there was no significant variation of water absorption with warp-yarn orientation.

In the tests on the MC2 molded V-panels (fig. 10(b)), the water absorption was less for the panels with the 0° warp-yarn orientation than for the panels with 45° and 90° orientation. This was true for the flat sections and the 45° and 90° curved sections. Also, there was some indication that the water absorption was less for the 45° and 90° curved sections than for the corresponding flat sections.

For the postformed PC2 panels, there was an increase in water absorption of the flat sections and formerly 45° curved sections only when the warp yarn was oriented 0°. This increase was approximately 20 percent. For the panels in which the warp yarn was oriented 45° and 90°, postforming did not affect the water absorption of these sections. The postformed formerly 90° curved sections, however, showed increases in water absorption ranging from approximately 10 to 30 percent for all three warp-yarn directions.

Both before and after postforming, the water absorption of the MC2 panels was greater than that of the MC1 panels.

DISCUSSION

Initial Properties of Sheet Materials

Most of the commercial phenolic-laminate sheets show a tendency to exhibit directional variation in mechanical properties as can be observed from table XVII. Approximately half of the materials show different strengths in the lengthwise and the crosswise directions. Most of the materials show different strengths in the lengthwise and the 45° directions. In most cases, the strengths are higher in the lengthwise direction.

The lower values noted in the crosswise direction when compared with those in the lengthwise direction may be due in part to differences in the yarns per inch of the cloth fabric in the two directions. The lower values in the 45° direction are probably due to the fact that in this direction the full strength of the yarns is not utilized.

The data indicate that, usually, for those materials in which the tensile strength is greater in one direction, the flexural strength is also greater in that direction.

The two samples SF1 and SF2 that exhibit very high strength values in the lengthwise direction have rather low strengths in the crosswise and 45° directions, probably indicating that the cloth yarns in this laminate were preferentially oriented (tables V, VI, VIII, and IX). It should be noted that the difference in yarns per inch in the two directions for the fabric used in these laminates is much greater than in any of the other laminates. None of the other materials show such a large difference in properties between the lengthwise and transverse directions.

The effect of laminating pressure on the properties of flat sheets can be observed by comparing the results obtained for the SC1 panels with those obtained for the SC2 panels. Both samples were made of similar materials. The laminating pressure used for the SC1 panels was 200 psi and that used for the SC2 panels was 1,000 psi. With one exception, the values for tensile strength, tensile modulus, flexural strength, and flexural modulus are greater for the SC2 panels than for the SC1 panels.

Properties of Heat-Treated Sheet Material

The slight changes in dimensions observed in most cases on heating the laminates represent a reversal of the changes in dimensions that occur during high-pressure laminating. The thickness increased slightly on heating and there was an indication of decrease in length and width. It is plausible to consider the phenolic resins as being partially thermoplastic, with the result that there is a slight tendency for the resin to assume its original dimensions when heated. This resulting increase in thickness would result in a tendency toward partial delamination of the laminate, leading to a decrease in strength properties which is observed as a result of the heating cycles.

Effect of Industrial Postforming on Properties of Flat Sections

The PG1 samples showed larger changes in flexural properties and water absorption due to postforming than did the PG2 samples. This is probably due to the fact that the postforming operation was much more severe for the former samples than for the latter. The postformed PG1 sample contained several 90° bends whereas the PG2 sample contained only one 30° bend. According to the fabricator, the same heating cycle was used in both cases.

The water-absorption results indicate that the greatest effects of postforming occur at the curved sections. It was noted that in these curved sections, the fabric was more prominent in the outer surface and numerous fine cracks appeared in the resin.

Properties of Molded Angles and Channels

The strength and modulus of flat portions from the commercially molded channels MB1 and angles MB2 are considerably less than those of flat sheets made from similar materials. However, the strength and modulus of the flat sections from the V-panels molded in the laboratory at the National Bureau of Standards are in most cases higher than those of similar flat sheets. These differences in behavior between commercially molded and laboratory-molded parts may be due to differences in fabrication conditions or techniques. Thus, it appears that the strength and modulus of flat portions of molded laminate sections may or may not be different from those of sheet laminates.

Effects of Postforming on Properties of Curved Sections

As stated previously, the strengths of the flat sections of the laboratory molded V-panels are in most cases higher than those of sheet laminates, whereas industrially molded parts have lower strength values. In addition, the postforming heating cycle did not affect the flexural strength of the flat sections of the V-panels in most cases, whereas the flexural strength of commercial sheet laminates decreased as much as approximately 10 percent on heating in most cases. These differences in behavior may be due to fabrication techniques.

The PC2 panels were made of materials used in postforming-grade laminates whereas the PC1 panels were not. This difference is reflected in the slightly higher flexural strengths of the postformed PC2 panels in two cases only, when specimens of the formerly curved sections with 0° and with 90° warp yarn were tested on the convex side. In addition, the water absorption is greater for the PC2 panels than for the PC1, both before and after postforming. However, the flexural modulus of elasticity of the PC2 panels was consistently greater than that of the PC1 panels, with one exception. These results would indicate that shapes postformed from postforming-grade laminates do not necessarily have superior properties for structural and semistructural applications than do those fabricated from regular-grade laminates.

In most cases, the strength of the formerly 90° curved sections was equal to or lower than that of the formerly 45° curved sections and the water absorption was higher. These latter results are in agreement with the results obtained on the commercially postformed shapes. These results would indicate that the higher the angle of bending, the more the properties of the material are affected.

In general, the flexural-strength values for the formerly curved sections when tested on the convex side were higher than when tested on the concave side. In postforming, compressive stresses are induced in one surface of the formerly curved sections and tensile stresses in the other. When the specimens are tested on the concave side, the side with the residual compressive stresses is in tension, and, when tested on the convex side, the side with the residual tensile stresses is in tension. One might therefore expect the specimens tested on the concave side to give higher strength values than the specimens tested on the convex side. Actually, the reverse was found to be true. One explanation is that there is probably a realinement of residual forces in the laminate when the pressure applied in postforming is removed because of the tendency of the material near the neutral axis to assume its original position. Because of this alinement, the face formerly in compression would now be in tension and vice versa. Thus, when the specimens are tested on the concave side, the face in tension already has a residual tensile stress, which would tend to decrease the flexural strength. The reverse is true for the convex side and results in higher strength values for the specimens when tested on the convex side than when tested on the concave side.

CONCLUDING REMARKS

Tests were conducted to determine the properties of flat sheets, molded shapes, and postformed shapes of cotton-fabric phenolic laminates. Most commercial cotton-fabric phenolic sheet laminates tested showed directional variations in mechanical properties. In most cases, the values obtained when the specimens were tested at a 45° orientation to the warp yarn in the top ply are up to 25 percent lower than those obtained when the specimens were tested lengthwise or crosswise. For materials in which the tensile strength and modulus were greater in one direction, the flexural strength and modulus also tended to be greater in that direction.

Postforming may or may not affect the strength properties of flat sections, probably depending on the fabrication technique and possibly the resins used. In general, the strength of curved sections decreased on postforming and the water absorption increased. The degree to which these properties changed increased as the bending angle increased. The flexural strength of postformed curved sections was higher when the load was applied to the convex side than when it was applied to the concave side.

The molding of shapes of phenolic laminates may or may not reduce the strength properties of the laminate, probably depending on the fabrication techniques.

National Bureau of Standards,
Washington, D. C., June 15, 1953.

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TABLE I.- DESCRIPTION OF COTTON-FABRIC PHENOLIC LAMINATES

NBS sample designation (a)	Type	Approximate size, in.	Fabric			
			Number of plies	Yarns per in.	Yarn, ply	Weave
SA1-16	Grade C postforming	70 by 46	4	39 by 34	1	Plain
SA2-16	Grade C infrared postforming	70 by 46	4	50 by 34	1,2	[b]Plain
SB1-16	Grade C natural postforming	9 by 8.5 9 by 3.75	4	38 by 38	1	Plain
SB2-16X	Grade C	36 by 36	4	40 by 38	2	Plain, 8.66-oz army duck
SB2-8X	Grade C	36 by 36	9	40 by 38	2	Plain, 8.66-oz army duck
SB2-4X	Grade C	36 by 36	16	40 by 38	2	Plain, 8.66-oz army duck
SB3-16Y	Grade CJP-11 postforming	36 by 36	4	40 by 38	1	Plain, 8.66-oz army duck
SB3-8Y	Grade CJP-11 postforming	36 by 36	9	40 by 38	1	Plain, 8.66-oz army duck
SB3-4Y	Grade CJP-11 postforming	36 by 36	16	40 by 38	1	Plain, 8.66-oz army duck
SC1-16X		10 by 10	4	40 by 38	2	Plain, 8.66-oz army duck
SC1-8X		10 by 10	9	40 by 38	2	Plain, 8.66-oz army duck
SC1-4X		10 by 10	16	40 by 38	2	Plain, 8.66-oz army duck
[c]SC2-16X		10 by 10	4	40 by 38	2	Plain, 8.66-oz army duck
SC2-8X		10 by 10	9	40 by 38	2	Plain, 8.66-oz army duck
SC2-4X		10 by 10	16	40 by 38	2	Plain, 8.66-oz army duck
SC3-16Y		10 by 10	4	40 by 38	1	Plain, 8.66-oz army duck
SC3-8Y		10 by 10	9	40 by 38	1	Plain, 8.66-oz army duck
SC3-4Y		10 by 10	16	40 by 38	1	Plain, 8.66-oz army duck
SD1-16		36 by 36	4	39 by 37	1	Plain
SE1-8	Grade C	36 by 36	7	50 by 34	1	Plain

[a]First letter indicates form: S indicates flat sheets, M indicates molded shapes, P indicates postformed shapes; second letter indicates source (letter C designates samples prepared at NBS); first number is sample number; number after dash is reciprocal of nominal thickness in inches; all materials with X in their designation are made with same resin and fabric and under similar molding conditions; all materials with Y in their designation are made with same resin and fabric and under similar molding conditions; in samples MC and PC, R indicates that warp yarns of outer plies were parallel to lengthwise direction of molded V-panel, S indicates that warp yarns of outer plies were at 45° to lengthwise direction of molded V-panel, and T indicates that warp yarns of outer plies were perpendicular to lengthwise direction of molded V-panel.

[b]Two-ply yarn in one direction, single ply in other.

[c]SC1 and SC2 differ only in that SC1 was molded at 200 psi and SC2, at 1,000 psi.

TABLE I.- DESCRIPTION OF COTTON-FABRIC PHENOLIC LAMINATES - Continued

NBS sample designation (a)	Type	Approximate size, in.	Fabric			
			Number of plies	Yarns per in.	Yarn, ply	Weave
SF1-16	Natural postforming	48 by 48	5	70 by 40	-	Twill, over 2 under 1
SF2-16	Green postforming	48 by 48	6	70 by 40	-	Twill, over 2 under 1
[d]MB1-16	Grade C	36 by 2.3 sides	4	52 by 42	1	Plain
[d]MB1-8	Grade C	36 by 2.3 sides	9	52 by 42	1	Plain
[d]MB1-4	Grade C	36 by 2.3 sides	16	52 by 42	1	Plain
[e]MB2-16	Grade C	36 by 2.3 sides and base	4	39 by 37	1	Plain
[e]MB2-8	Grade C	36 by 2.3 sides and base	9	39 by 37	1	Plain
[e]MB2-4	Grade C	36 by 2.3 sides and base	16	39 by 37	1	Plain
[f]MC1-16XR		5 by 4	4	40 by 38	2	Plain, 8.66-oz army duck
[f]MC1-16XS		5 by 4	4	40 by 38	2	Plain, 8.66-oz army duck
[f]MC1-16XT		5 by 4	4	40 by 38	2	Plain, 8.66-oz army duck
[f]MC2-16YR		5 by 4	4	40 by 38	1	Plain, 8.66-oz army duck
[f]MC2-16YS		5 by 4	4	40 by 38	1	Plain, 8.66-oz army duck
[f]MC2-16YT		5 by 4	4	40 by 38	1	Plain, 8.66-oz army duck
[g]PC1-16XR	Postformed from MC1-16XR	5 by 4	4	40 by 38	2	Plain, 8.66-oz army duck
[g]PC1-16XS	Postformed from MC1-16XS	5 by 4	4	40 by 38	2	Plain, 8.66-oz army duck
[g]PC1-16XT	Postformed from MC1-16XT	5 by 4	4	40 by 38	2	Plain, 8.66-oz army duck

[a]First letter indicates form: S indicates flat sheets, M indicates molded shapes, P indicates postformed shapes; second letter indicates source (letter C designates samples prepared at NBS); first number is sample number; number after dash is reciprocal of nominal thickness in inches; all materials with X in their designation are made with same resin and fabric and under similar molding conditions; all materials with Y in their designation are made with same resin and fabric and under similar molding conditions; in samples MC and PC, R indicates that warp yarns of outer plies were parallel to lengthwise direction of molded V-panel, S indicates that warp yarns of outer plies were at 45° to lengthwise direction of molded V-panel, and T indicates that warp yarns of outer plies were perpendicular to lengthwise direction of molded V-panel.

[d]Molded angles; natural color.

[e]Molded channels; natural color.

[f]Molded V-panels; see fig. 1.

[g]V-panels postformed into flat sheets.

TABLE I.- DESCRIPTION OF COTTON-FABRIC PHENOLIC LAMINATES - Concluded

NBS sample designation (a)	Type	Approximate size, in.	Fabric: Number of plies	Fabric: Yarns per in.	Fabric: Yarn ply	Fabric: Weave
[g]PC2-16YR	Postformed from MC2-16YR	5 by 4	4	40 by 38	1	Plain, 8.66-oz army duck
[g]PC2-16YS	Postformed from MC2-16YS	5 by 4	4	40 by 38	1	Plain, 8.66-oz army duck
[g]PC2-16YT	Postformed from MC2-16YT	5 by 4	4	40 by 38	1	Plain, 8.66-oz army duck
[h]PG1-16	Postformed from SB1-16	9 by 2.5 base and three sides	4	38 by 38	1	Plain
[i]PG2-16	Postformed from SB1-16	9 by 3.75 with 30° bend 1.75 in. from one end	4	38 by 38	1	Plain

[a]First letter indicates form: S indicates flat sheets, M indicates molded shapes, P indicates postformed shapes; second letter indicates source (letter C designates samples prepared at NBS); first number is sample number; number after dash is reciprocal of nominal thickness in inches; all materials with X in their designation are made with same resin and fabric and under similar molding conditions; all materials with Y in their designation are made with same resin and fabric and under similar molding conditions; in samples MC and PC, R indicates that warp yarns of outer plies were parallel to lengthwise direction of molded V-panel, S indicates that warp yarns of outer plies were at 45° to lengthwise direction of molded V-panel, and T indicates that warp yarns of outer plies were perpendicular to lengthwise direction of molded V-panel.

[g]V-panels postformed into flat sheets.

[h]Ammunition chute part from B-25 nose assembly, channel; see fig. 2.

[i]Ammunition chute part from B-25 nose assembly; see fig. 3.

TABLE II.- DIMENSIONAL CHANGES PRODUCED BY POSTFORMING HEAT TREATMENTS ON COTTON-FABRIC

PHENOLIC SHEET LAMINATE

NBS sample designation	Immersion in oil at 375° F (a)						Heating in circulating air oven at 400° F					
	Duration of heating, sec	Average original thickness, in.	Average thickness after heating, in.	Change in thickness on heating, percent	Change in length, percent	Change in width, percent	Duration of heating, min	Average original thickness, in.	Average thickness after heating, in.	Change in thickness on heating, percent	Change in length, percent	Change in width, percent
SA1-16							1	0.0648	0.0651	0.4	-0.5	-0.2
	20	0.0654	0.0656	0.2	0	-0.4	2	.0647	.0650	.4	-.2	-.3
	40	.0664	.0669	.7	-.7	-.4	3.5	.0654	.0674	3.0	-.9	-.6
SA2-16	[b]30	.0679	.0689	1.5	-.7	-1.0	3	.0692	.0708	2.4	-.3	-1.0
	[b]60	.0680	.0693	1.9	-.3	-1.0	5	.0686	.0710	3.5	-1.0	-1.0
	[b]120	.0699	.0713	2.0	-1.0	-1.0						
SB1-16	[b]30	.0643	.0650	1.1	0	-1.0	2	.0642	.0652	1.6	-.3	0
	[b]60	.0706	.0712	.8	-.7	-.5	3	.0631	.0637	1.0	0	-1.0
	[b]120	.0652	.0640	1.3	-.3	0						
SD1-16	25	.0655	.0654	-.2	-.4	-.2	1	.0654	.0651	-.5	0	-.1
	35	.0655	.0656	.2	-.4	-.2	2	.0650	.0652	.3	-.4	-.2
	45	.0662	.0659	-.4	-.4	-.4	3	.0649	.0655	.9	-.4	-.3
SE1-8	60	.1245	.1257	1.0	-.5	-.2	3	.1259	.1259	0	0	-.1
	120	.1253	.1280	2.2	-.2	-.5	6	.1289	.1311	2.4	-.2	-.2
SF1-16	25	.0749	.0761	1.6	-.5	-.3	1	.0743	.0745	.2	0	0
	35	.0739	.0768	3.2	-.4	-.4	2	.0750	.0771	2.6	-.2	-.2
	[b]35	.0736	.0788	7.1	.3	-1.0	3	.0741	.0757	2.1	-.9	-.4
	50	.0748	.0869	13.9	-.7	-.9						
	[b]50	.0725	.0797	9.9	-.7	-.5						
SF2-16	25	.0692	.0696	.6	-.2	-.1	1	.0698	.0695	-.4	-.2	0
	35	.0701	.0720	2.6	-.2	-.2	2	.0694	.0700	.8	-.2	-.1
							3	.0695	.0694	-.1	-.2	-.2

[a]SAE 20 oil containing 10 percent sulfur was used for oil immersion except where otherwise noted.
[b]Markol paraffin oil.

TABLE III.- EFFECT OF OVEN HEATING AT 204.5° C (400° F) ON FLEXURAL PROPERTIES OF COTTON-FABRIC PHENOLIC SHEET LAMINATES

NBS sample designation	Time of heating, min	Flexural strength (a): Number of tests	Flexural strength (a): Average, psi	Flexural strength (a): Range, psi	Flexural strength (a): Standard error, psi	Flexural strength (a): Coefficient of variation, percent	Flexural strength (a): Percent of original	Flexural modulus of elasticity (a): Number of tests	Flexural modulus of elasticity (a): Average, psi	Flexural modulus of elasticity (a): Range, psi	Flexural modulus of elasticity (a): Standard error, psi	Flexural modulus of elasticity (a): Coefficient of variation, percent	Flexural modulus of elasticity (a): Percent of original
SA1-16	0	10	19,900	18,800 to 20,300	100	1.6	100	9	0.92×10^6	0.81×10^6 to 0.97×10^6	0.018×10^6	5.8	100
	1	5	19,300	19,000 to 19,500	110	1.3	97.0	5	.93	.89 to 0.95	.011	2.7	101
	2	5	19,200	18,900 to 19,500	140	1.5	96.4	4	.84	.78 to 0.90	.021	5.1	91.2
	3.5	5	18,300	18,000 to 18,600	120	1.5	91.8	5	.84	.80 to 0.89	.010	2.8	91.2
SA2-16	0	5	18,200	17,800 to 18,800	200	2.4	100	5	.94	.89 to 0.99	.016	3.9	100
	3	5	17,300	17,100 to 17,700	100	1.4	95.0	5	.80	.74 to 0.84	.017	4.7	85.1
	5	5	17,300	17,000 to 17,800	150	2.0	95.0	5	.77	.75 to 0.79	.008	2.2	82.0
SB1-16	0	5	17,600	17,200 to 17,900	150	1.9	100	5	.83	.78 to 0.88	.016	4.4	100
	2	4	17,600	17,000 to 18,200	280	3.2	100	3	.82	.80 to 0.85	----	---	98.8
	3	6	16,800	15,500 to 17,900	370	5.4	95.4	6	.79	.74 to 0.82	.013	4.2	95.2
SD1-16	0	10	19,900	19,300 to 20,400	100	1.6	100	10	.96	.91 to 1.00	.009	3.0	100
	1	5	19,900	18,400 to 20,500	410	4.6	100	3	1.00	.98 to 1.03	----	---	104
	2	5	19,500	19,100 to 19,700	110	1.3	98.0	5	.97	.94 to 1.00	.011	2.5	101
	2	4	19,100	19,100 to 19,100	0	0	96.0	4	.97	.93 to 0.99	.013	2.7	101
	3	5	19,500	18,900 to 20,100	200	2.2	98.0	5	.93	.89 to 0.97	.015	3.6	96.8
SE1-8	0	19	[b]20,100	19,400 to 20,600	80	1.7	100	19	.91	.88 to 0.94	.004	2.1	100
	3	5	[b]18,700	18,400 to 19,000	110	1.3	93.0	5	.84	.81 to 0.89	.010	4.1	92.2
	6	5	[b]18,900	18,400 to 19,400	160	2.0	94.0	5	.88	.84 to 0.90	.012	3.1	96.6
	0	10	[c]21,000	19,100 to 21,600	140	2.0	100	10	.97	.94 to 1.00	.006	1.9	100
	3	5	[c]19,900	19,200 to 20,500	220	2.4	94.7	4	.98	.91 to 1.02	.024	4.9	101
	6	5	[c]19,400	19,000 to 19,600	80	.9	92.3	4	.91	.87 to 0.97	.022	4.8	93.8
	0	10	19,400	19,100 to 19,900	90	1.4	100	10	.91	.88 to 0.94	.008	2.7	100
	3	5	18,400	18,000 to 18,800	140	1.7	94.8	4	.87	.85 to 0.88	.008	1.8	95.6
	6	5	17,900	17,600 to 18,200	120	1.5	92.1	5	.84	.82 to 0.87	.009	2.3	92.3

[a]Specimens tested 45° to lengthwise unless otherwise indicated.

[b]Tested lengthwise.

[c]Tested crosswise.

TABLE III.- EFFECT OF OVEN HEATING AT 204.5° C (400° F) ON FLEXURAL PROPERTIES

OF COTTON-FABRIC PHENOLIC SHEET LAMINATES - Concluded

NBS sample designation	Time of heating, min	Flexural strength (a)						Flexural modulus of elasticity (a)					
		Number of tests	Average psi	Range, psi	Standard error, psi	Coefficient of variation, percent	Percent of original	Number of tests	Average psi	Range, psi	Standard error, psi	Coefficient of variation, percent	Percent of original
SF1-16	0	11	19,600	18,600 to 20,100	160	2.7	100	11	1.04×10^6	0.97×10^6 to 1.11×10^6	0.012×10^6	3.8	100
	1	5	19,400	18,800 to 19,700	160	1.9	98.9	3	.94	.93 to 0.95	----------	---	90.3
	2	5	17,500	17,100 to 17,900	140	1.9	89.2	4	.90	.90 to 0.90	0	0	86.5
	2	4	17,500	17,200 to 18,000	180	2.0	89.2	4	.90	.85 to 0.95	.024	5.3	86.5
	3	5	18,100	18,000 to 18,400	80	.9	92.3	5	.89	.85 to 0.91	.010	2.6	85.5
SF2-16	0	11	16,600	15,800 to 17,200	140	2.7	100	11	1.05	.92 to 1.16	.032	9.5	100
	1	5	16,500	16,100 to 17,800	320	4.3	99.3	5	.88	.87 to 0.89	.004	1.0	83.8
	2	5	16,100	15,700 to 16,300	100	1.5	96.9	5	.88	.84 to 0.93	.016	4.0	83.8
	2	4	16,500	16,400 to 16,600	60	.7	99.3	4	.93	.91 to 1.00	.022	4.8	88.5
	3	5	16,900	16,800 to 17,000	40	.5	102	3	.91	.87 to 0.94	.014	3.4	86.6

[a]Specimens tested 45° to lengthwise unless otherwise indicated.

TABLE IV.- EFFECT OF IMMERSION IN OIL AT 190.5° C (375° F) ON FLEXURAL PROPERTIES

OF COTTON-FABRIC PHENOLIC SHEET LAMINATES

NBS sample designation	Time of immersion, sec (a)	Flexural strength (b)					Flexural modulus of elasticity (b)				
		Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Percent of original	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Percent of original
SA1-16	0	10	19,900	100	1.6	100	9	0.92×10^6	0.018×10^6	5.8	100
	20	5	19,300	200	2.3	97.0	5	.94	.026	6.2	102
	40	5	19,000	120	1.4	95.4	5	.90	.047	11.7	97.8
SA2-16	0	5	18,200	200	2.4	100	5	.94	.016	3.9	100
	[c]30	5	16,900	240	3.2	92.8	5	.89	.018	4.4	94.6
	[c]60	5	16,700	90	1.2	91.7	5	.90	.011	2.8	95.8
	[c]120	5	16,600	130	1.8	91.2	5	.90	.009	2.2	95.8
SB1-16	0	6	17,100	450	6.9	100	6	.80	.005	1.5	100
	[c]30	6	16,600	190	2.8	97.0	5	.79	.013	4.2	98.7
	[c]60	6	17,000	140	2.1	99.3	6	.84	.012	3.4	105
	[c]120	4	16,500	150	1.8	96.4	4	.88	.020	4.6	110
SD1-16	0	10	19,900	100	1.6	100	10	.96	.009	3.0	100
	25	5	19,300	40	.5	97.0	5	.93	.007	1.7	96.8
	35	4	19,100	60	.7	96.0	4	.85	.013	3.1	88.5
	45	5	19,300	70	.8	97.0	5	.91	.022	5.5	94.7
	45	4	19,400	80	.8	97.5	4	.92	.018	3.9	95.8
SE1-8	0	19	[d]20,100	80	1.7	100	19	.91	.004	2.1	100
	60	5	[d]18,500	120	1.4	92.0	5	.84	.010	2.7	92.2
	120	5	[d]18,100	250	3.1	90.0	5	.80	.010	3.0	87.8
	0	10	[e]21,000	140	2.0	100	10	.97	.006	1.9	100
	60	5	[e]20,000	110	1.2	95.2	5	.91	.010	2.5	93.8
	120	5	[e]18,600	130	1.6	88.5	5	.87	.007	1.9	89.6
	0	10	19,400	90	1.4	100	10	.91	.008	2.7	100
	60	5	18,700	80	.9	96.3	5	.84	.007	2.0	92.3
	120	5	17,800	110	1.4	91.6	5	.81	.007	2.0	89.0

[a]Immersion in SAE 20 lubricating oil containing 10 percent sulfur unless otherwise noted.

[b]Specimens tested 45° to lengthwise unless otherwise indicated.

[c]Immersion in Markol paraffin oil instead of lubricating oil.

[d]Tested lengthwise.

[e]Tested crosswise.

TABLE IV.- EFFECT OF IMMERSION IN OIL AT 190.5° C (375° F) ON FLEXURAL PROPERTIES

OF COTTON-FABRIC PHENOLIC SHEET LAMINATES - Concluded

NBS sample designation	Time of immersion, sec (a)	Flexural strength (b)					Flexural modulus of elasticity (b)				
		Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Percent of original	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Percent of original
SF1-16	0	11	19,600	160	2.7	100	11	1.04×10^6	0.012×10^6	3.8	100
	25	5	18,600	230	2.7	94.8	5	.98	.036	8.3	94.2
	25	4	17,400	170	1.9	88.7	4	.95	.032	6.6	91.3
	35	5	18,400	210	2.5	93.8	5	.95	.024	5.6	91.3
	[c]35	5	15,100	140	2.1	77.0	5	.77	.010	3.0	74.0
	50	5	18,100	160	2.0	92.3	5	.91	.020	5.0	87.5
	[c]50	5	15,600	90	1.3	79.5	3	.81	-----------	---	77.9
SF2-16	0	11	16,600	140	2.8	100	11	1.05	.030	9.5	100
	25	5	16,200	100	1.4	97.5	5	.93	.013	3.1	88.5
	25	4	16,300	40	.5	98.0	4	.91	0	0	86.6
	35	5	16,100	140	1.9	96.9	5	1.12	.041	8.3	107

[a]Immersion in SAE 20 lubricating oil containing 10 percent sulfur unless otherwise noted.

[b]Specimens tested 45° to lengthwise unless otherwise indicated.

[c]Immersion in Markol paraffin oil instead of lubricating oil.

TABLE V.- TENSILE STRENGTH OF COTTON-FABRIC

PHENOLIC SHEET LAMINATES

NBS sample designation	Average thickness, in.	Number of sheets	Tensile strength, lengthwise, (a)				Tensile strength, crosswise, (a)				Tensile strength at 45° (a)			
			Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
SA1-16	0.064	1	5	11,900	140	2.6	5	9,400	70	1.8	5	9,000	70	1.8
SA2-16	.069	1	5	9,000	30	.8	5	8,900	60	1.5	5	8,900	30	.8
SB1-16	.065	3	12	11,300	190	5.7	9	9,600	200	6.1	9	10,000	240	7.8
SB2-16X	.068	1	14	9,700	150	5.9	15	9,800	210	8.2	15	8,500	120	5.2
SB2-8X	.134	1	5	11,700	170	3.3	5	11,600	160	3.2	5	9,800	30	.7
SB2-4X	.269	1	5	10,100	150	3.3	5	10,900	100	2.1	5	10,100	100	2.1
SB3-16Y	.065	1	9	12,000	210	5.3	9	10,800	450	12.5	10	10,100	90	2.8
SB3-8Y	.133	1	5	12,400	70	1.2	5	10,600	260	5.4	5	9,500	90	2.1
SB3-4Y	.245	1	5	11,700	60	1.1	5	12,000	120	2.2	5	9,300	80	2.0
SC1-16X	.070	1	5	9,700	120	2.7	---	------	---	----	---	------	---	---
SC1-8X	.152	1	5	9,900	110	2.5	---	------	---	----	---	------	---	---
SC1-4X	.270	1	5	10,600	260	5.5	---	------	---	----	---	------	---	---
SC2-16X	.064	1	5	10,400	170	3.6	---	------	---	----	---	------	---	---
SC2-8X	.141	1	5	11,000	220	4.4	---	------	---	----	---	------	---	---
SC2-4X	.243	1	5	10,000	170	3.7	---	------	---	----	---	------	---	---
SC3-16Y	.053	2	10	10,500	140	4.1	---	------	---	----	---	------	---	---
SC3-8Y	.115	2	10	11,600	150	4.1	---	------	---	----	---	------	---	---
SC3-4Y	.228	2	10	12,400	120	3.0	---	------	---	----	---	------	---	---
SD1-16	.063	1	5	10,300	140	2.9	5	9,400	100	2.4	5	9,400	80	2.0
SE1-8	.123	1	5	11,500	70	1.3	5	11,300	100	1.9	5	10,000	190	4.3
SF1-16	.073	1	5	15,000	90	1.3	5	8,400	70	1.9	5	9,300	40	.9
SF2-16	.067	1	5	16,900	200	2.6	5	7,800	100	2.7	5	8,300	70	1.8

[a]Lengthwise, crosswise, and 45° indicate that warp yarns on face plies were parallel, perpendicular, and at 45°, respectively, to length of test specimen.

TABLE VI.- TENSILE SECANT MODULUS OF ELASTICITY OF COTTON-FABRIC

PHENOLIC SHEET LAMINATES

NBS sample designation (a)	Tensile secant modulus of elasticity											
	Lengthwise (b)				Crosswise (b)				45° to lengthwise (b)			
	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
Stress range, 0 to 2,500 psi												
SA1-16	5	1.26×10^6	0.006×10^6	1.1	5	1.16×10^6	0.018×10^6	3.4	5	1.13×10^6	0.010×10^6	1.9
SA2-16	5	1.24	.020	3.7	5	1.21	.020	3.8	5	1.11	.018	3.7
SB1-16	9	1.08	.013	3.7	8	.98	.028	8.0	9	.88	.017	5.8
SB2-16X	13	1.01	.020	7.2	13	1.00	.020	7.2	15	.92	.014	5.8
SB2-8X	5	1.23	.030	5.4	4	1.17	.069	11.7	4	1.02	.016	3.1
SB2-4X	4	1.01	.028	5.5	5	1.06	.034	7.2	5	1.02	.026	5.7
SB3-16Y	8	1.25	.034	7.8	10	1.20	.021	5.5	10	1.21	.026	6.7
SB3-8Y	5	1.11	.033	6.7	5	1.14	.018	3.5	5	1.09	.029	6.0
SB3-4Y	5	1.10	.027	5.6	5	1.09	.029	5.9	5	.96	.018	4.1
SC1-16X	5	.86	.012	3.0	--	----------	----------	---	--	----------	----------	---
SC1-8X	5	.85	.012	3.2	--	----------	----------	---	--	----------	----------	---
SC1-4X	5	.81	.022	6.1	--	----------	----------	---	--	----------	----------	---
SC2-16X	5	.96	.018	4.2	--	----------	----------	---	--	----------	----------	---
SC2-8X	5	1.04	.018	3.9	--	----------	----------	---	--	----------	----------	---
SC2-4X	5	.88	.017	4.3	--	----------	----------	---	--	----------	----------	---
SC3-16Y	10	.97	.007	2.1	--	----------	----------	---	--	----------	----------	---
SC3-8Y	9	1.09	.016	4.5	--	----------	----------	---	--	----------	----------	---
SC3-4Y	10	1.13	.014	3.8	--	----------	----------	---	--	----------	----------	---
SD1-16	5	1.19	.015	2.8	5	1.25	.010	1.7	5	1.10	.013	2.7
SE1-8	5	1.14	.038	7.4	5	1.22	.030	5.5	5	1.06	.018	3.7
SF1-16	4	1.30	.031	4.8	5	1.05	.024	5.2	5	1.11	.016	3.3
SF2-16	5	1.31	.017	2.8	5	.88	.016	4.1	5	1.02	.013	2.9

[a]Average thickness and number of sheets represented are given in table V.

[b]Lengthwise, crosswise, and 45° to lengthwise indicate that warp yarns on face plies were parallel, perpendicular, and at 45°, respectively, to length of test specimen.

TABLE VI.- TENSILE SECANT MODULUS OF ELASTICITY OF COTTON-FABRIC

PHENOLIC SHEET LAMINATES - Continued

NBS sample designation (a)	Tensile secant modulus of elasticity											
	Lengthwise (b)				Crosswise (b)				45° to lengthwise (b)			
	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
Stress range, 0 to 5,000 psi												
SA1-16	5	1.19×10^{6}	0.017×10^{6}	3.1	5	1.08×10^{6}	0.011×10^{6}	2.4	5	1.05×10^{6}	0.013×10^{6}	2.9
SA2-16	5	1.14	.012	2.4	5	1.13	.013	2.6	5	1.04	.010	2.3
SB1-16	9	.96	.007	2.1	8	.85	.011	3.6	9	.78	.010	3.7
SB2-16X	13	.87	.016	6.5	13	.87	.019	7.7	15	.81	.012	5.8
SB2-8X	5	1.14	.018	3.5	4	1.06	.057	10.7	3	.97	.024	4.3
SB2-4X	5	.85	.012	3.2	5	.93	.011	2.8	4	.87	.020	4.5
SB3-16Y	8	1.12	.030	7.5	10	1.09	.017	5.0	10	1.13	.022	6.2
SB3-8Y	5	1.03	.020	4.3	5	1.04	.021	4.5	5	1.00	.018	4.1
SB3-4Y	5	.96	.016	3.7	5	.97	.011	2.6	5	.86	.011	2.8
SC1-16X	5	.71	.019	6.1	--	----------	----------	---	--	----------	----------	---
SC1-8X	4	.72	.005	1.4	--	----------	----------	---	--	----------	----------	---
SC1-4X	5	.67	.009	3.0	--	----------	----------	---	--	----------	----------	---
SC2-16X	5	.81	.015	4.0	--	----------	----------	---	--	----------	----------	---
SC2-8X	5	.87	.014	3.5	--	----------	----------	---	--	----------	----------	---
SC2-4X	5	.74	.015	4.6	--	----------	----------	---	--	----------	----------	---
SC3-16Y	10	.82	.008	3.0	--	----------	----------	---	--	----------	----------	---
SC3-8Y	9	.97	.014	4.3	--	----------	----------	---	--	----------	----------	---
SC3-4Y	10	1.04	.007	2.3	--	----------	----------	---	--	----------	----------	---
SD1-16	5	1.11	.010	2.0	5	1.14	.006	1.2	5	1.00	.005	1.2
SE1-8	5	1.03	.027	5.8	5	1.10	.025	6.0	5	.97	.015	3.5
SF1-16	4	1.22	.011	1.8	5	.94	.014	3.3	5	1.02	.021	4.7
SF2-16	5	1.20	.008	1.6	5	.66	.010	3.6	5	.89	.009	2.2

[a]Average thickness and number of sheets represented are given in table V.

[b]Lengthwise, crosswise, and 45° to lengthwise indicate that warp yarns on face plies were parallel, perpendicular, and at 45°, respectively, to length of test specimen.

TABLE VI.- TENSILE SECANT MODULUS OF ELASTICITY OF COTTON-FABRIC

PHENOLIC SHEET LAMINATES - Concluded

NBS sample designation (a)	Tensile secant modulus of elasticity											
	Lengthwise (b)				Crosswise (b)				45° to lengthwise (b)			
	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
Stress range, 0 to 7,500 psi												
SB2-16X	8	0.68 × 10^6	0.013 × 10^6	5.5	--	--	--	--	--	--	--	--
SB2-8X	5	.97	.009	2.1	4	0.90 × 10^6	0.029 × 10^6	6.4	3	0.82 × 10^6	0.028 × 10^6	6.0
SB2-4X	5	.63	.024	8.5	5	.74	.013	4.0	4	.70	.010	3.0
SB3-16Y	8	.99	.026	7.3	10	.93	.033	11.1	10	1.03	.027	8.2
SB3-8Y	5	.92	.023	5.6	5	.94	.013	3.1	5	.90	.012	3.0
SB3-4Y	5	.79	.013	3.7	5	.81	.005	1.7	4	.75	.008	2.2
SC1-16X	5	.54	.059	39.4	--	--	--	--	--	--	--	--
SC1-8X	-	--	--	--	--	--	--	--	--	--	--	--
SC1-4X	5	.54	.019	12.4	--	--	--	--	--	--	--	--
SC2-16X	5	.58	.014	5.3	--	--	--	--	--	--	--	--
SC2-8X	5	.68	.023	7.5	--	--	--	--	--	--	--	--
SC2-4X	5	.47	.063	30.0	--	--	--	--	--	--	--	--
SC3-16Y	10	.48	.014	9.2	--	--	--	--	--	--	--	--
SC3-8Y	9	.76	.013	5.0	--	--	--	--	--	--	--	--
SC3-4Y	10	.84	.007	2.7	--	--	--	--	--	--	--	--

[a]Average thickness and number of sheets represented are given in table V.

[b]Lengthwise, crosswise, and 45° to lengthwise indicate that warp yarns on face plies were parallel, perpendicular, and at 45°, respectively, to length of test specimen.

TABLE VII.- STRAIN AT FAILURE IN TENSILE TESTS OF COTTON-FABRIC

PHENOLIC SHEET LAMINATES

NBS sample designation	Strain at failure (2-in. gage length)											
	Lengthwise (a)				Crosswise (a)				45° to lengthwise (a)			
	Number of tests	Average, percent	Standard error, percent	Coefficient of variation, percent	Number of tests	Average, percent	Standard error, percent	Coefficient of variation, percent	Number of tests	Average, percent	Standard error, percent	Coefficient of variation, percent
SA1-16	5	2.9	0.07	5.6	5	2.8	0.13	10.3	5	2.6	0.16	14.2
SA2-16	5	2.2	.25	25.0	5	2.3	.24	24.0	5	1.7	.05	7.0
SB1-16	8	4.4	.21	13.2	9	5.4	.18	10.1	9	7.5	.28	11.2
SD1-16	5	3.8	.15	9.0	5	4.3	.14	7.1	5	5.3	.24	10.1
SE1-8	4	4.6	.19	8.2	5	4.9	.26	11.9	5	6.5	.08	2.9
SF1-16	2	3.6	----	----	4	3.3	.24	14.3	5	1.8	.06	7.2
SF2-16	3	5.2	.09	4.0	5	6.4	.21	7.4	5	7.4	.25	7.5

[a]Lengthwise, crosswise, and 45° to lengthwise indicate that warp yarns on face plies were parallel, perpendicular, and at 45°, respectively, to length of test specimen.

TABLE VIII.- FLEXURAL STRENGTH OF COTTON-FABRIC

PHENOLIC SHEET LAMINATES

NBS sample designation	Average thickness, in.	Number of sheets	Flexural strength, lengthwise (a)				Flexural strength, crosswise (a)				Flexural strength at 45° (a)			
			Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
SA1-16	0.065	1	5	24,300	370	3.4	5	20,000	340	3.8	16	19,700	120	2.5
SA2-16	.069	1	5	19,700	150	1.7	5	18,600	200	2.4	5	18,200	200	2.4
SB1-16	.064	6	21	20,900	150	3.2	20	19,300	230	5.4	20	18,200	140	3.5
SB2-16X	-----	1	15	18,500	290	5.9	15	18,600	320	6.7	15	17,700	350	7.7
SB2-8X	-----	1	5	20,800	260	2.8	5	20,800	250	2.7	5	19,400	120	1.4
SB2-4X	-----	1	5	17,500	270	3.5	5	18,100	160	2.0	5	16,500	60	.8
[b]SB2-4X	-----	1	5	15,800	300	4.2	5	16,900	330	4.4	5	15,500	220	3.2
SB3-16Y	-----	1	10	23,200	140	2.0	10	23,200	220	3.0	10	21,800	140	2.0
SB3-8Y	-----	1	5	22,800	250	2.4	5	21,200	220	2.4	5	20,200	240	2.7
SB3-4Y	-----	1	5	20,400	150	1.7	5	20,400	110	1.2	5	17,600	190	1.9
SC1-16X	-----	1	5	16,800	220	3.8	5	16,400	160	2.2	5	14,900	70	1.0
SC1-8X	-----	1	5	17,200	90	1.0	5	17,700	110	1.3	5	16,300	60	.8
SC1-4X	-----	1	---	-----	---	---	5	17,000	130	1.7	3	15,700	70	.8
SC2-16X	-----	1	5	19,800	110	1.2	5	19,200	180	2.1	5	16,900	130	1.8
SC2-8X	-----	1	5	20,000	200	2.2	5	19,600	150	1.7	5	18,400	70	.8
SC2-4X	-----	1	---	-----	---	---	5	19,600	240	2.8	5	17,700	80	1.1
SC3-16Y	-----	2	10	20,700	240	3.6	10	19,000	240	3.0	10	17,100	200	3.7
SC3-8Y	-----	2	10	21,300	310	4.5	10	21,700	110	1.5	10	19,500	100	1.6
SC3-4Y	-----	2	---	-----	---	---	10	20,500	280	4.4	10	18,800	90	1.6
SD1-16	.063	1	5	21,500	260	2.7	5	21,800	320	3.3	10	19,900	100	1.5
SE1-8	.123	1	19	20,100	80	1.7	10	21,000	140	2.0	10	19,400	90	1.4
SF1-16	.073	1	5	26,000	350	3.0	5	16,500	160	2.1	11	19,600	160	2.7
SF2-16	.067	1	5	23,800	210	2.0	5	16,700	280	3.8	11	16,600	140	2.7

[a]Lengthwise, crosswise, and 45° indicate that warp yarns on face plies were parallel, perpendicular, and at 45°, respectively, to length of test specimen.

[b]Specimens tested with lamina vertical (edgewise) instead of in usual horizontal manner (flatwise).

TABLE IX.- FLEXURAL MODULUS OF ELASTICITY OF COTTON-FABRIC

PHENOLIC SHEET LAMINATES

NBS sample designation (a)	Flexural modulus of elasticity, lengthwise (b)				Flexural modulus of elasticity, crosswise (b)				Flexural modulus of elasticity, at 45° (b)			
	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
SA1-16	4	1.18×10^6	0.026×10^6	4.5	5	1.04×10^6	0.046×10^6	9.8	16	0.90×10^6	0.053×10^6	5.3
SA2-16	5	1.10	.010	2.1	5	.99	.021	4.8	5	.94	.016	3.9
SB1-16	20	.94	.014	6.7	17	.93	.015	6.6	20	.86	.010	5.1
SB2-16X	14	.82	.027	11.9	15	.90	.014	6.0	13	.85	.011	4.7
SB2-8X	5	1.10	.008	1.6	4	1.13	.050	8.8	5	1.03	.013	2.8
SB2-4X	5	.90	.018	4.4	5	.97	.006	1.3	5	.88	.018	4.6
[c]SB2-4X	5	.73	.023	7.0	5	.85	.036	9.6	5	.76	.010	2.8
SB3-16Y	10	1.07	.020	5.8	10	1.12	.018	5.1	10	1.08	.014	4.0
SB3-8Y	5	1.16	.036	7.0	5	1.11	.026	5.4	5	1.06	.024	5.0
SB3-4Y	5	1.03	.022	4.8	5	1.02	.012	2.7	5	.94	.015	3.6
SC1-16X	4	.73	.011	3.0	5	.80	.017	4.9	5	.78	.031	8.8
SC1-8X	5	.80	.024	6.6	5	.80	.017	4.6	5	.76	.007	1.9
SC1-4X	---	-------	-------	----	5	.83	.011	2.9	4	.82	.030	7.3
SC2-16X	5	.86	.013	3.4	5	.90	.014	3.3	5	.82	.020	5.6
SC2-8X	5	.97	.015	3.5	5	.93	.016	3.8	5	.86	.014	3.7
SC2-4X	--	-------	-------	----	5	1.00	.015	3.3	5	.86	.005	1.3
SC3-16Y	10	.89	.012	4.4	10	.86	.012	4.5	10	.86	.013	4.8
SC3-8Y	9	1.03	.018	5.2	10	1.00	.016	5.2	10	.96	.011	3.7
SC3-4Y	--	-------	-------	----	10	1.09	.012	3.4	10	1.01	.013	4.0
SD1-16	5	1.12	.024	4.8	5	1.12	.031	6.2	10	.96	.009	3.0
SE1-8	19	.91	.004	2.1	10	.97	.006	1.9	10	.91	.008	2.7
SF1-16	5	1.20	.025	4.7	5	.99	.030	6.8	11	1.04	.012	3.8
SF2-16	5	1.16	.034	6.8	4	.80	.029	7.2	11	1.05	.032	9.5

[a]Average thickness and number of sheets represented are given in table VIII.

[b]Lengthwise, crosswise, and at 45° indicate that warp yarns on face plies were parallel, perpendicular, and at 45°, respectively, to length of test specimen.

[c]Specimens tested with lamina vertical (edgewise) instead of in usual horizontal manner (flatwise).

TABLE X.- EFFECT OF INDUSTRIAL POSTFORMING ON PROPERTIES OF

COTTON-FABRIC PHENOLIC SHEET LAMINATE

Property (a)	Sample SB1-16				Sample PG1-16					Sample PG2-16				
	Number of tests (b)	Average	Standard error	Coefficient of variation, percent	Number of tests (b)	Average	Standard error	Coefficient of variation, percent	Percent of original	Number of tests (b)	Average	Standard error	Coefficient of variation, percent	Percent of original
Tensile test														
Strength, psi														
Lengthwise	12	11,300	190	5.7	12	10,400	210	6.9	92	--	----------	----------	---	---
Modulus of elasticity, psi														
Lengthwise	9	1.08×10^6	0.013×10^6	5.7	6	1.00×10^6	0.025×10^6	6.0	93	--	----------	----------	---	---
Strain at failure, percent														
Lengthwise	8	4.4	0.21	13.2	11	5.0	0.08	5.3	114	--	----------	----------	---	---
Flexural test														
Strength, psi														
Lengthwise	21	20,900	150	3.2	8	18,500	180	2.7	89	12	19,600	100	1.8	94
Crosswise	20	19,300	250	5.4	9	16,500	220	3.9	85	11	18,500	160	2.8	96
At 45°	20	18,200	140	3.5	8	16,000	440	7.8	88	12	17,600	130	2.6	97
Modulus of elasticity, psi														
Lengthwise	20	0.94×10^6	0.014×10^6	6.7	7	0.87×10^6	0.014×10^6	4.3	93	8	0.91×10^6	0.018×10^6	5.5	97
Crosswise	17	0.93×10^6	0.015×10^6	6.6	9	0.83×10^6	0.018×10^6	6.7	89	11	0.90×10^6	0.016×10^6	5.9	97
At 45°	20	0.86×10^6	0.010×10^6	5.1	8	0.74×10^6	0.022×10^6	8.3	86	12	0.90×10^6	0.013×10^6	4.8	105
Water absorption														
24-hour immersion														
Flat section, percent	15	2.5	----------	---	3	2.4	----------	---	96	3	2.8	----------	---	112
Curved section, percent	---	----------	----------	---	6	[c]3.7	----------	---	148	4	[d]3.0	----------	---	120
48-hour immersion														
Flat section, percent	10	3.5	----------	---	2	3.3	----------	---	94	2	3.0	----------	---	86
Curved section, percent	---	----------	----------	---	4	[c]5.1	----------	---	146	2	[d]3.7	----------	---	106
72-hour immersion														
Flat section, percent	5	3.5	----------	---	1	4.3	----------	---	123	1	3.4	----------	---	97
Curved section, percent	---	----------	----------	---	2	[c]5.8	----------	---	166	1	[d]4.5	----------	---	129

[a]Units apply only to columns entitled "Average" and "Standard error."

[b]Each group of test specimens was cut from three pieces or parts.

[c]90° curved section.

[d]50° curved section.

TABLE XI.- TENSILE PROPERTIES OF CHANNELS AND ANGLES MOLDED OF

COTTON-FABRIC PHENOLIC LAMINATES

Sample designation	Tensile strength (a)				Tensile modulus of elasticity, range from 0 to 2,500 psi (a)				Tensile modulus of elasticity, range from 0 to 5,000 psi (a)			
	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
MB1-16	10	6,000	270	14.0	11	0.84×10^6	0.039×10^6	15.7	10	0.68×10^6	0.035×10^6	15.4
MB1-8	12	7,000	240	11.7	12	.94	.046	17.0	12	.81	.038	16.3
MB1-4	12	7,000	120	5.7	12	.96	.023	8.2	12	.82	.018	7.6
MB2-16	7	5,900	170	7.5	7	.80	.014	4.7	7	.68	.020	8.0
MB2-8	8	6,700	260	11.0	6	.92	.032	8.5	6	.78	.043	13.6
MB2-4	8	6,900	90	3.9	8	.96	.027	8.0	8	.80	.014	4.9

[a]Long dimension of specimen was parallel to length of channels and angles.

TABLE XII.- FLEXURAL PROPERTIES OF CHANNELS AND ANGLES MOLDED

OF COTTON-FABRIC PHENOLIC LAMINATES

NBS sample designation	Side of specimen in tension	Flexural strength (a)				Flexural modulus of elasticity (a)			
		Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent	Number of tests	Average, psi	Standard error, psi	Coefficient of variation, percent
MB1-16	Molded	12	14,900	640	15.0	10	0.70×10^6	0.033×10^6	14.7
	Machined	12	13,300	560	14.6	11	.74	.039	17.2
MB1-8	Molded	12	16,200	680	14.5	12	.85	.030	12.4
	Machined	11	14,800	540	12.2	11	.86	.021	8.3
MB1-4	Molded	12	14,800	220	5.2	12	.79	.015	6.4
	Machined	12	13,600	270	6.7	12	.81	.013	5.4
MB2-16	Molded	12	14,200	370	9.0	6	.69	.031	10.9
	Machined	12	14,400	210	5.1	4	.77	.024	6.2
MB2-8	Molded	12	15,500	290	6.5	12	.79	.015	6.7
	Machined	11	13,400	370	9.2	11	.81	.019	7.7
MB2-4	Molded	12	15,400	120	2.6	12	.85	.008	3.5
	Machined	12	13,200	220	5.7	12	.86	.008	3.3

[a]Long dimension of specimens was parallel to length of channels and angles.

TABLE XIII.- DIFFERENCES IN STRENGTH PROPERTIES BETWEEN FLAT SHEET SAMPLE SB2 AND CHANNELS AND ANGLES MOLDED OF COTTON-FABRIC PHENOLIC LAMINATES

[Differences are expressed as a percentage of values for flat sheets.]

NBS sample designation	Difference in tensile strength, lengthwise, percent	Difference in tensile secant modulus of elasticity; range, 0 to 2,500 psi, percent	Difference in flexural strength, lengthwise, percent	Difference in flexural modulus of elasticity, lengthwise, percent
MB1-16	-38	-17	-20	-15
MB2-16	-39	-21	-23	-16
MB1-8	-40	-24	-22	-23
MB2-8	-43	-25	-26	-28
MB1-4	-31	-5	-15	-12
MB2-4	-32	-5	-12	-8

TABLE XIV.- FLEXURAL STRENGTH OF FLAT SHEETS POSTFORMED

FROM MOLDED V-PANELS

NBS sample designation	Orientation, deg (a)	Load (b)	Number of panels tested	Flexural strength of flat section				Flexural strength of formerly 45° curved section				Flexural strength of formerly 90° curved section				Strength ratio		
				Number of tests	Average, psi	Standard error, psi	CV, percent (c)	Number of tests	Average, psi	Standard error, psi	CV, percent (c)	Number of tests	Average, psi	Standard error, psi	CV, percent (c)	45° curved to flat section	90° curved to flat section	90° curved to 45° curved section
MC1-16XR	0	-------	1	7	[d]20,800	30	1.5	--	------	---	----	--	------	---	----	----	----	----
PC1-16XR	0	Convex	3	26	20,000	250	6.3	21	13,500	670	22.8	12	13,400	710	18.2	0.68	0.67	0.99
PC1-16XR	0	Concave	3	32	20,400	190	5.3	25	15,500	150	4.6	14	12,200	140	4.4	.67	.60	.76
PC1-16XS	45	Convex	3	29	18,300	110	3.2	28	20,300	200	5.3	14	21,400	210	3.6	1.11	1.17	1.05
PC1-16XS	45	Concave	3	30	18,100	77	2.3	28	13,900	95	3.6	14	11,700	91	2.9	.77	.65	.84
PC1-16XT	90	Convex	4	36	20,200	140	4.0	33	16,100	590	21.1	19	15,400	780	22.1	.80	.76	.96
PC1-16XT	90	Concave	4	39	20,200	110	3.5	36	15,400	110	4.3	21	12,200	81	3.1	.76	.60	.79
MC2-16YR	0	-------	1	7	[d]22,200	450	5.0	--	------	---	----	--	------	---	----	----	----	----
MC2-16YS	45	-------	1	7	[d]18,900	410	6.0	--	------	---	----	--	------	---	----	----	----	----
MC2-16YT	90	-------	1	7	[d]19,400	630	3.0	--	------	---	----	--	------	---	----	----	----	----
PC2-16YR	0	Convex	3	15	21,600	200	3.5	15	21,500	370	6.6	15	23,000	540	9.1	1.00	1.06	1.07
PC2-16YR	0	Concave	3	15	21,200	330	6.0	14	16,000	210	4.9	14	12,400	160	4.9	.75	.58	.78
PC2-16YS	45	Convex	3	15	18,000	110	2.4	15	20,700	300	5.6	15	22,900	380	6.3	1.15	1.27	1.11
PC2-16YS	45	Concave	3	15	17,100	130	3.0	15	13,600	120	3.4	15	11,100	150	5.1	.80	.65	.82
PC2-16YT	90	Convex	3	15	20,400	390	7.5	15	21,400	320	5.9	15	23,000	580	10.0	1.05	1.13	1.07
PC2-16YT	90	Concave	3	15	19,700	310	6.9	15	15,400	220	5.5	15	12,500	140	4.4	.78	.63	.81

[a]Orientation of warp yarn to longitudinal axis of molded V-section.

[b]Load applied at center of former curve; longitudinal axis of former curve was at 90° to length of test specimens.

[c]CV, coefficient of variation.

[d]Flexural strength of flat section prior to postforming.

TABLE XV.- FLEXURAL MODULUS OF ELASTICITY OF FLAT SHEETS

POSTFORMED FROM MOLDED V-PANELS

NBS sample designation	Orientation, deg (a)	Load (b)	Number of panels tested	Flexural modulus of elasticity of flat section				Flexural modulus of elasticity of formerly 45° curved section				Flexural modulus of elasticity of formerly 90° curved section				Modulus ratio		
				Number of tests	Average, psi	Standard error, psi	CV, percent (c)	Number of tests	Average, psi	Standard error, psi	CV, percent (c)	Number of tests	Average, psi	Standard error, psi	CV, percent (c)	45° curved to flat section	90° curved to flat section	90° curved to 45° curved section
MC1-16XR	0	-------	1	7	[d]1.24×10^6	0.026×10^6	6											
PC1-16XR	0	Convex	3	18	.94	.019	9	12	0.81×10^6	0.032×10^6	14	12	0.74×10^6	0.032×10^6	15	0.86	0.79	0.91
PC1-16XR	0	Concave	3	16	.98	.018	12	12	.81	.017	7	12	.75	.026	12	.83	.77	.93
PC1-16XB	45	Convex	3	16	.88	.015	7	14	.85	.015	7	14	.86	.017	7	.97	.98	1.01
PC1-16XB	45	Concave	3	16	.84	.010	5	14	.80	.014	7	14	.76	.016	8	.95	.90	.95
PC1-16XT	90	Convex	4	25	.95	.017	8	20	.85	.026	14	20	.80	.031	17	.89	.84	.94
PC1-16XT	90	Concave	4	24	.96	.010	5	21	.84	.015	9	21	.82	.017	11	.88	.85	.98
MC2-16YR	0	-------	1	7	[d]1.01	.035	9	--	-------	-------	--	--	-------	-------	--	---	---	---
MC2-16YB	45	-------	1	7	[d]1.02	.033	9	--	-------	-------	--	--	-------	-------	--	---	---	---
MC2-16YT	90	-------	1	7	[d].95	.017	5	--	-------	-------	--	--	-------	-------	--	---	---	---
PC2-16YR	0	Convex	3	15	1.18	.020	6	15	1.18	.028	9	13	1.18	.025	8	1.00	1.00	1.00
PC2-16YR	0	Concave	3	15	1.18	.019	6	14	1.08	.034	12	14	.99	.021	8	.92	.84	.92
PC2-16YB	45	Convex	3	15	.99	.015	6	15	1.16	.023	8	14	1.16	.046	15	1.17	1.17	1.00
PC2-16YB	45	Concave	3	15	.99	.018	7	15	.95	.011	5	15	.90	.036	16	.96	.91	.95
PC2-16YT	90	Convex	3	15	1.04	.010	4	15	1.13	.022	8	15	1.11	.025	9	1.09	1.07	.98
PC2-16YT	90	Concave	3	15	1.01	.027	10	15	.95	.025	10	15	.81	.053	25	.94	.80	.85

[a]Orientation of warp yarn to longitudinal axis of molded V-section.

[b]Load applied at center of former curve; longitudinal axis of former curve was at 90° to length of test specimens.

[c]CV, coefficient of variation.

[d]Flexural modulus of elasticity of flat section prior to postforming.

TABLE XVI.- WATER ABSORPTION OF PARTS FROM MOLDED V-PANELS

BEFORE AND AFTER POSTFORMING

NBS sample designation (a)	Orientation, deg (b)	Period of immersion, hr	Water absorption of flat section			Water absorption of initial or formerly 45° curved section			Water absorption of initial or formerly 90° curved section			Water absorption ratio		
			Number of panels (c)	Average, percent	Range, percent	Number of panels (c)	Average, percent	Range, percent	Number of panels (c)	Average, percent	Range, percent	45° curved to flat section	90° curved to flat section	90° curved to 45° curved section
MC1-16XR	0	24	4	2.93	2.80 to 3.10	4	2.90	2.80 to 3.00	5	2.88	2.80 to 3.00	0.99	0.98	0.99
MC1-16XR	0	48	1	4.38	----------	1	4.16	----------	1	4.25	----------	.95	.97	1.02
MC1-16XR	0	72	1	5.00	----------	1	4.94	----------	1	4.84	----------	.99	.97	.98
MC1-16XS	45	24	5	3.00	2.64 to 3.42	5	2.75	2.57 to 2.94	5	2.62	2.45 to 2.71	.92	.87	.95
MC1-16XS	45	48	1	4.03	----------	1	3.85	----------	1	3.69	----------	.96	.92	.96
MC1-16XS	45	72	1	4.52	----------	1	4.47	----------	1	4.30	----------	.99	.95	.96
MC1-16XT	90	24	4	3.19	2.95 to 3.60	2	2.79	2.76 to 2.81	3	2.85	2.68 to 2.94	.87	.89	1.01
MC1-16XT	90	48	1	4.34	----------	1	----	----------	1	4.06	----------	----	.94	----
MC1-16XT	90	72	1	5.86	----------	1	4.03	----------	1	4.65	----------	.69	.79	1.15
PC1-16XR	0	24	5	3.19	3.04 to 3.35	5	3.63	3.44 to 3.85	5	4.37	3.94 to 4.86	1.14	1.37	1.20
PC1-16XS	45	24	5	3.28	3.12 to 3.50	5	3.31	2.84 to 3.58	4	3.93	3.45 to 4.43	1.01	1.20	1.19
PC1-16XT	90	24	4	2.93	2.82 to 3.14	4	3.32	3.04 to 3.55	4	3.98	3.79 to 4.22	1.13	1.36	1.20
MC2-16XR	0	24	5	5.45	3.51 to 7.15	5	5.27	4.52 to 6.38	5	4.75	3.88 to 5.66	.97	.87	.90
MC2-16XR	0	48	1	6.56	----------	1	6.18	----------	1	5.78	----------	.94	.88	.94
MC2-16XR	0	72	1	7.24	----------	1	6.80	----------	1	6.39	----------	.94	.88	.94
MC2-16XS	45	24	5	8.77	8.58 to 8.88	5	7.99	7.62 to 8.41	4	7.20	6.82 to 7.69	.91	.82	.90
MC2-16XS	45	48	1	9.63	----------	1	8.89	----------	1	7.54	----------	.92	.78	.85
MC2-16XS	45	72	1	10.12	----------	1	9.28	----------	1	7.71	----------	.92	.76	.83

[a]Samples PC1 and PC2 were postformed from samples MC1 and MC2.

[b]Orientation of warp yarn to longitudinal axis of molded V-section.

[c]Three similar specimens were taken from each panel.

TABLE XVI.- WATER ABSORPTION OF PARTS FROM MOLDED V-PANELS

BEFORE AND AFTER POSTFORMING - Concluded

NBS sample designation (a)	Orientation, deg (b)	Period of immersion, hr	Water absorption of flat section			Water absorption of initial or formerly 45° curved section			Water absorption of initial or formerly 90° curved section			Water absorption ratio		
			Number of panels (c)	Average, percent	Range, percent	Number of panels (c)	Average, percent	Range, percent	Number of panels (c)	Average, percent	Range, percent	45° curved to flat section	90° curved to flat section	90° curved to 45° curved section
MC2-16XT	90	24	5	8.06	7.22 to 8.63	5	6.87	6.18 to 7.86	4	6.79	6.30 to 7.28	0.85	0.84	0.99
MC2-16XT	90	48	1	8.39	------------	1	7.36	------------	1	7.11	------------	.86	.85	.97
MC2-16XT	90	72	1	9.16	------------	1	7.63	------------	1	7.58	------------	.83	.83	.99
PC2-16XR	0	24	4	6.65	5.56 to 7.79	5	6.23	5.45 to 6.86	5	6.27	5.48 to 6.87	.94	.94	1.01
PC2-16XB	45	24	5	8.20	7.59 to 8.97	4	7.77	7.46 to 7.94	5	8.29	7.84 to 9.60	.95	1.01	1.07
PC2-16XT	90	24	5	7.83	7.52 to 8.09	5	7.10	6.48 to 7.53	5	7.45	7.14 to 7.81	.91	.95	1.05
Ratio of values for postformed to values for original panels														
PC1 to MC1	0	24	-	1.09	------------	-	1.26	------------	-	1.52	------------	----	----	----
	45	24	-	1.09	------------	-	1.21	------------	-	1.50	------------	----	----	----
	90	24	-	0.92	------------	-	1.19	------------	-	1.41	------------	----	----	----
PC2 to MC2	0	24	-	1.22	------------	-	1.19	------------	-	1.32	------------	----	----	----
	45	24	-	.94	------------	-	.97	------------	-	1.15	------------	----	----	----
	90	24	-	.97	------------	-	1.04	------------	-	1.10	------------	----	----	----

[a] Samples PC1 and PC2 were postformed from samples MC1 and MC2.

[b] Orientation of warp yarn to longitudinal axis of molded V-section.

[c] Three similar specimens were taken from each panel.

TABLE XVII.- COMPARISON OF MECHANICAL PROPERTIES OF THREE ORIENTATIONS OF

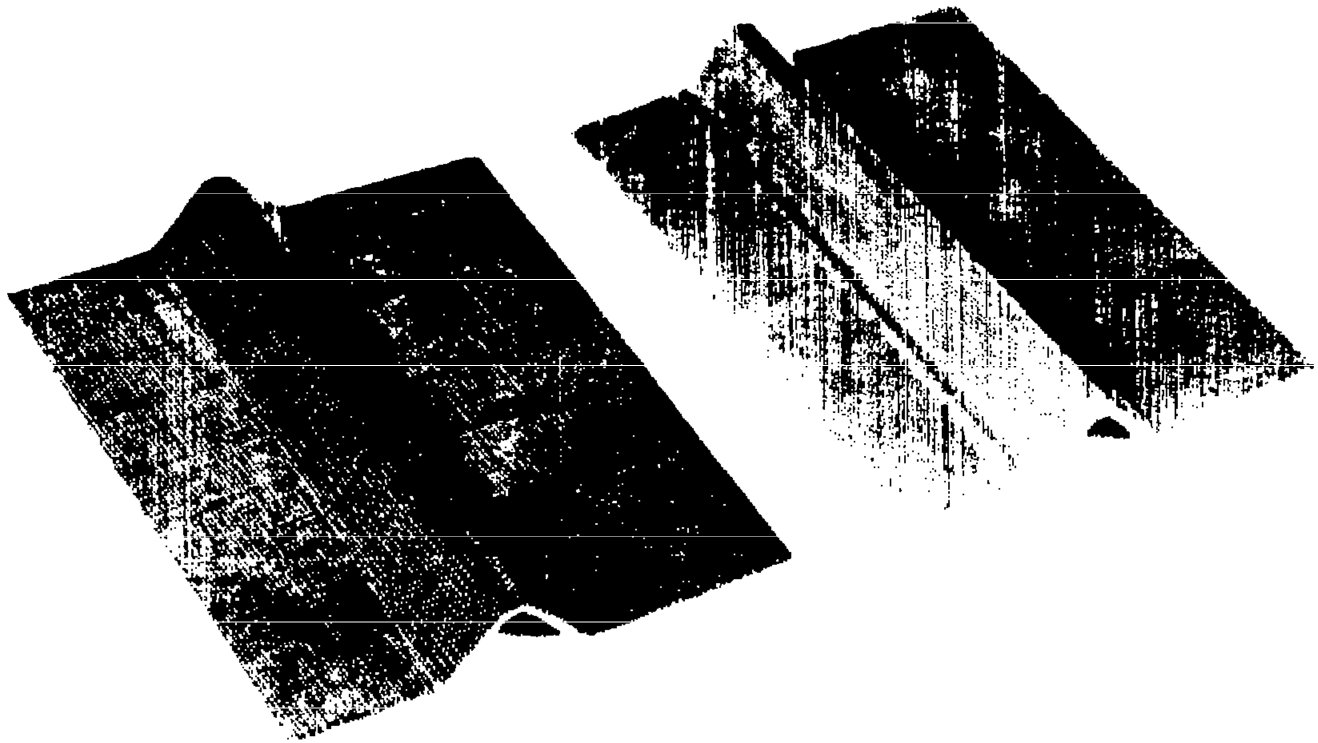
COTTON-FABRIC PHENOLIC SHEET LAMINATES

NBS sample designation	Orientation	Ratio for property value in direction indicated to that of lengthwise orientation						
		Tensile strength	Tensile modulus of elasticity for range -			Tensile strain	Flexural strength	Flexural modulus of elasticity
			0 to 2,500 psi	0 to 5,000 psi	0 to 7,500 psi			
SA1-16	Lengthwise	1.00	1.00	1.00	----	1.00	1.00	1.00
	Crosswise	.79	.92	.91	----	.97	.82	.88
	45°	.76	.90	.88	----	.90	.81	.76
SA2-16	Lengthwise	1.00	1.00	1.00	----	1.00	1.00	1.00
	Crosswise	.99	.97	.99	----	1.05	.94	.90
	45°	.99	.90	.91	----	.77	.92	.85
SB1-16	Lengthwise	1.00	1.00	1.00	----	1.00	1.00	1.00
	Crosswise	.85	.91	.89	----	1.23	.92	.99
	45°	.88	.81	.81	----	1.70	.87	.91
SB2-16X	Lengthwise	1.00	1.00	1.00	----	----	1.00	1.00
	Crosswise	1.01	.99	1.00	----	----	1.01	1.10
	45°	.88	.91	.93	----	----	.96	1.04
SB2-8X	Lengthwise	1.00	1.00	1.00	1.00	----	1.00	1.00
	Crosswise	.99	.95	.93	.93	----	1.00	1.03
	45°	.84	.83	.85	.85	----	.93	.94
SB2-4X	Lengthwise	1.00	1.00	1.00	1.00	----	1.00	1.00
	Crosswise	1.08	1.05	1.09	1.17	----	1.03	1.08
	45°	1.00	1.01	1.02	1.11	----	.94	1.11
SB3-16Y	Lengthwise	1.00	1.00	1.00	1.00	----	1.00	1.00
	Crosswise	.90	.96	.97	.94	----	1.00	1.05
	45°	.84	.97	1.01	1.04	----	.94	1.01

TABLE XVII.- COMPARISON OF MECHANICAL PROPERTIES OF THREE ORIENTATIONS OF

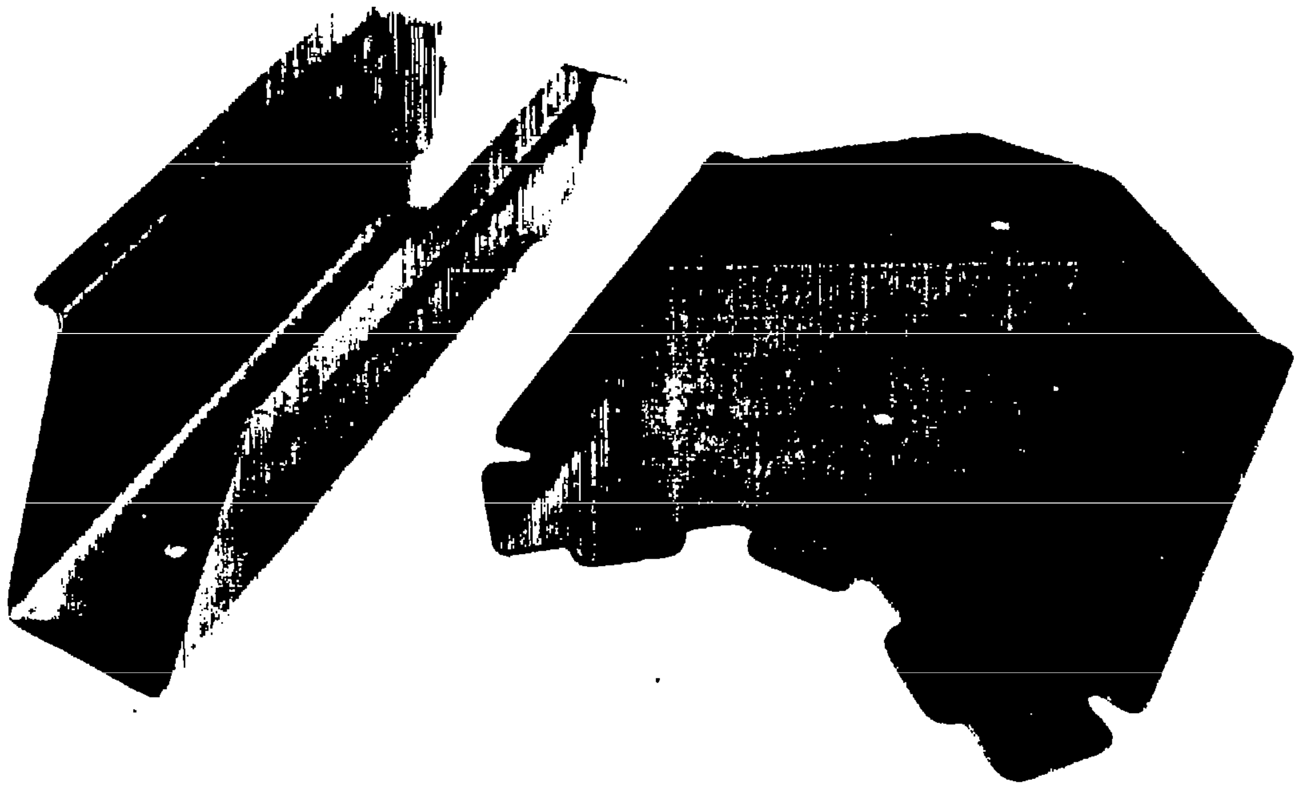
COTTON-FABRIC PHENOLIC SHEET LAMINATES - Concluded

NBS sample designation	Orientation	Ratio for property value in direction indicated to that of lengthwise orientation						
		Tensile strength	Tensile modulus of elasticity for range -			Tensile strain	Flexural strength	Flexural modulus of elasticity
			0 to 2,500 psi	0 to 5,000 psi	0 to 7,500 psi			
SB3-8Y	Lengthwise	1.00	1.00	1.00	1.00	-----	1.00	1.00
	Crosswise	.85	1.03	1.01	1.02	-----	.93	.96
	45°	.77	.98	.97	.98	-----	.89	.91
SB3-4Y	Lengthwise	1.00	1.00	1.00	1.00	-----	1.00	1.00
	Crosswise	1.02	.99	1.01	1.03	-----	1.00	.99
	45°	.79	.87	.90	.95	-----	.86	.91
SD1-16	Lengthwise	1.00	1.00	1.00	----	1.00	1.00	1.00
	Crosswise	.90	1.05	1.03	----	1.13	1.01	1.00
	45°	.90	.92	.90	----	1.39	.93	.86
SE1-8	Lengthwise	1.00	1.00	1.00	----	1.00	1.00	1.00
	Crosswise	.98	1.07	1.07	----	1.07	1.04	1.07
	45°	.87	.92	.94	----	1.41	.96	1.00
SF1-16	Lengthwise	1.00	1.00	1.00	----	1.00	1.00	1.00
	Crosswise	.56	.81	.77	----	.92	.63	.82
	45°	.62	.85	.84	----	.50	.75	.87
SF2-16	Lengthwise	1.00	1.00	1.00	----	1.00	1.00	1.00
	Crosswise	.46	.67	.55	----	1.23	.70	.69
	45°	.49	.78	.74	----	1.42	.70	.91



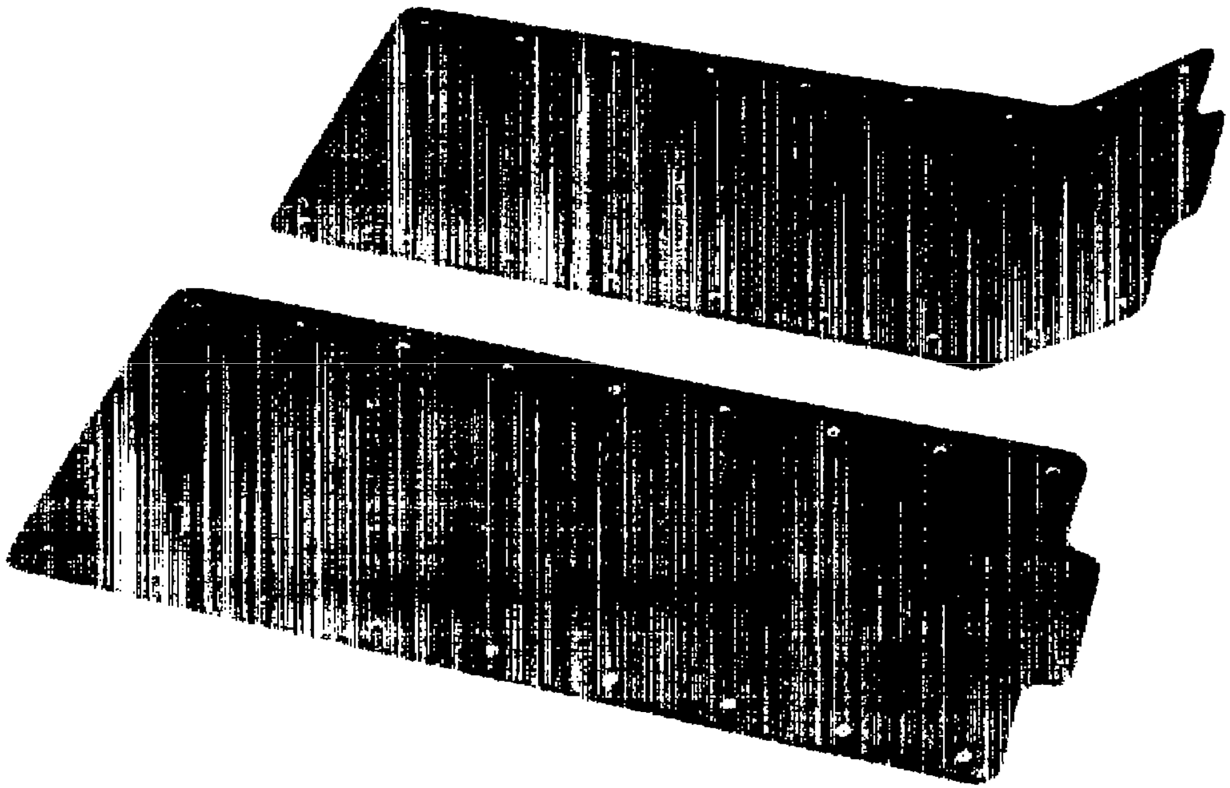
L-93548

Figure 1.- Molded V-sections, samples MC1 and MC2.



L-93549

Figure 2.- Postforming blank and ammunition chute part postformed from blank (samples SB1 and PG1, respectively).



L-93550

Figure 3.- Postforming blank and ammunition chute part postformed from blank (samples SB1 and PG2, respectively).

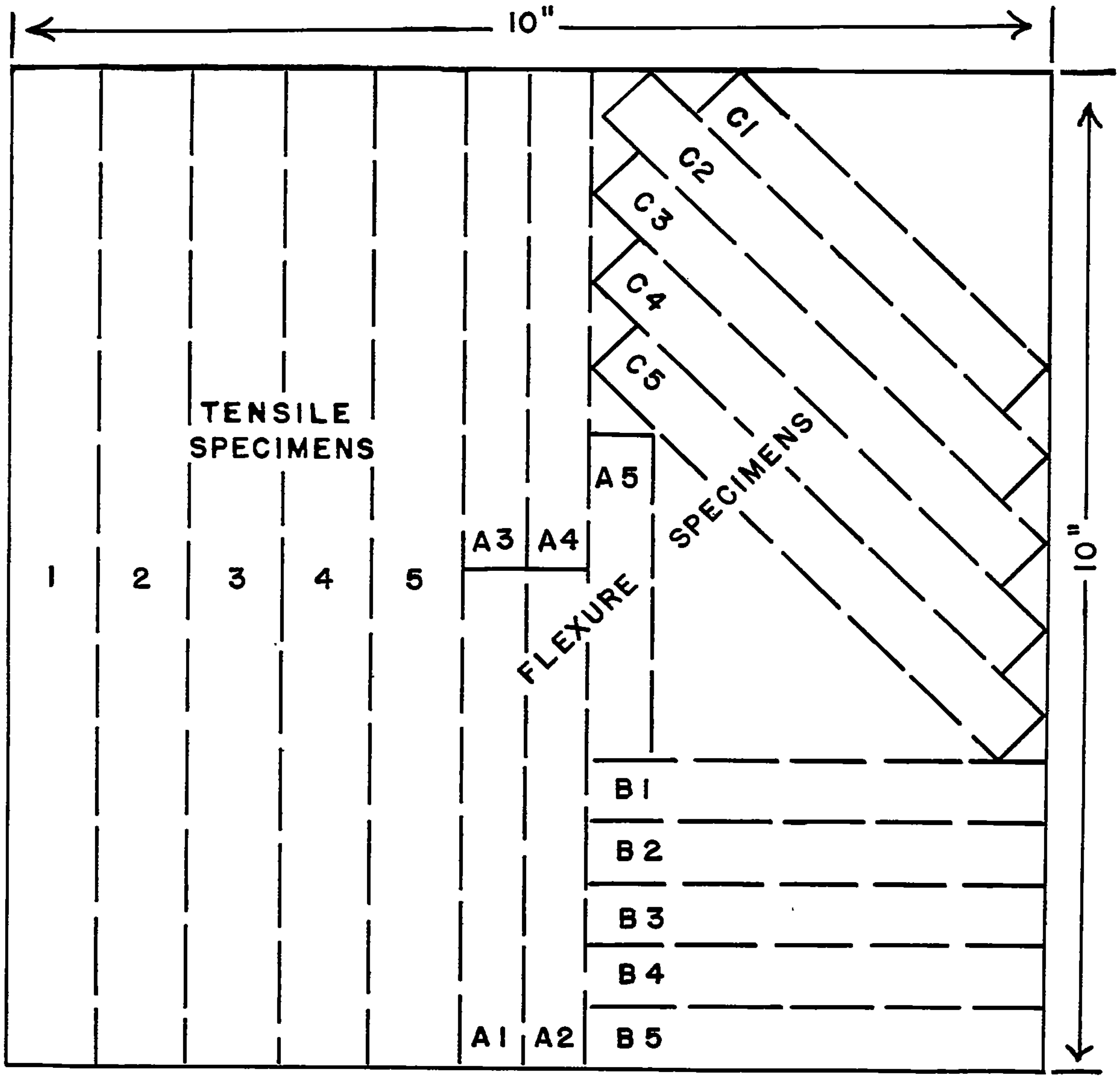


Figure 4.- Orientation of specimens from flat sheets, samples SC1, SC2, and SC3.

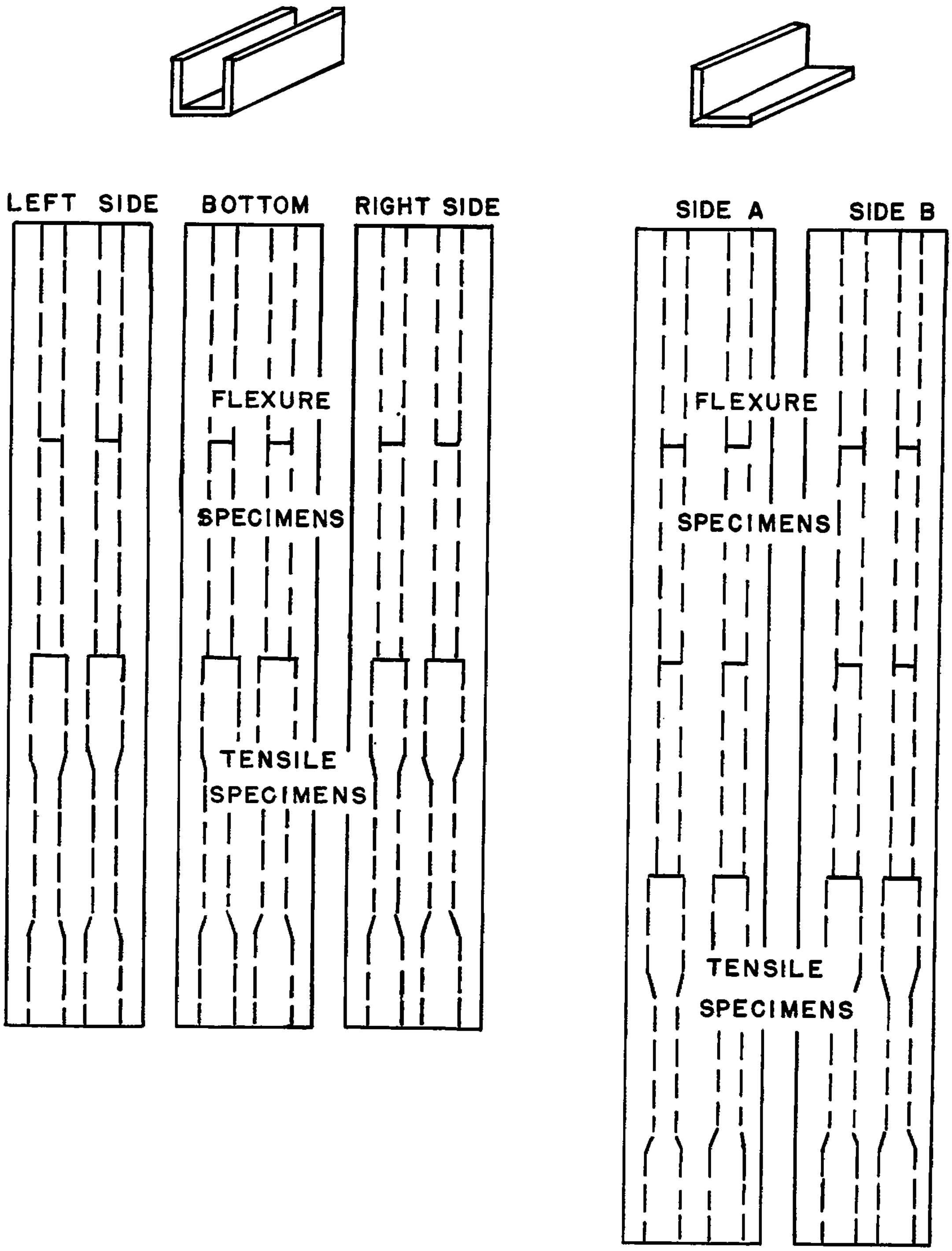


Figure 5.- Orientation of specimens from molded angles and channels, samples MB1 and MB2, respectively.

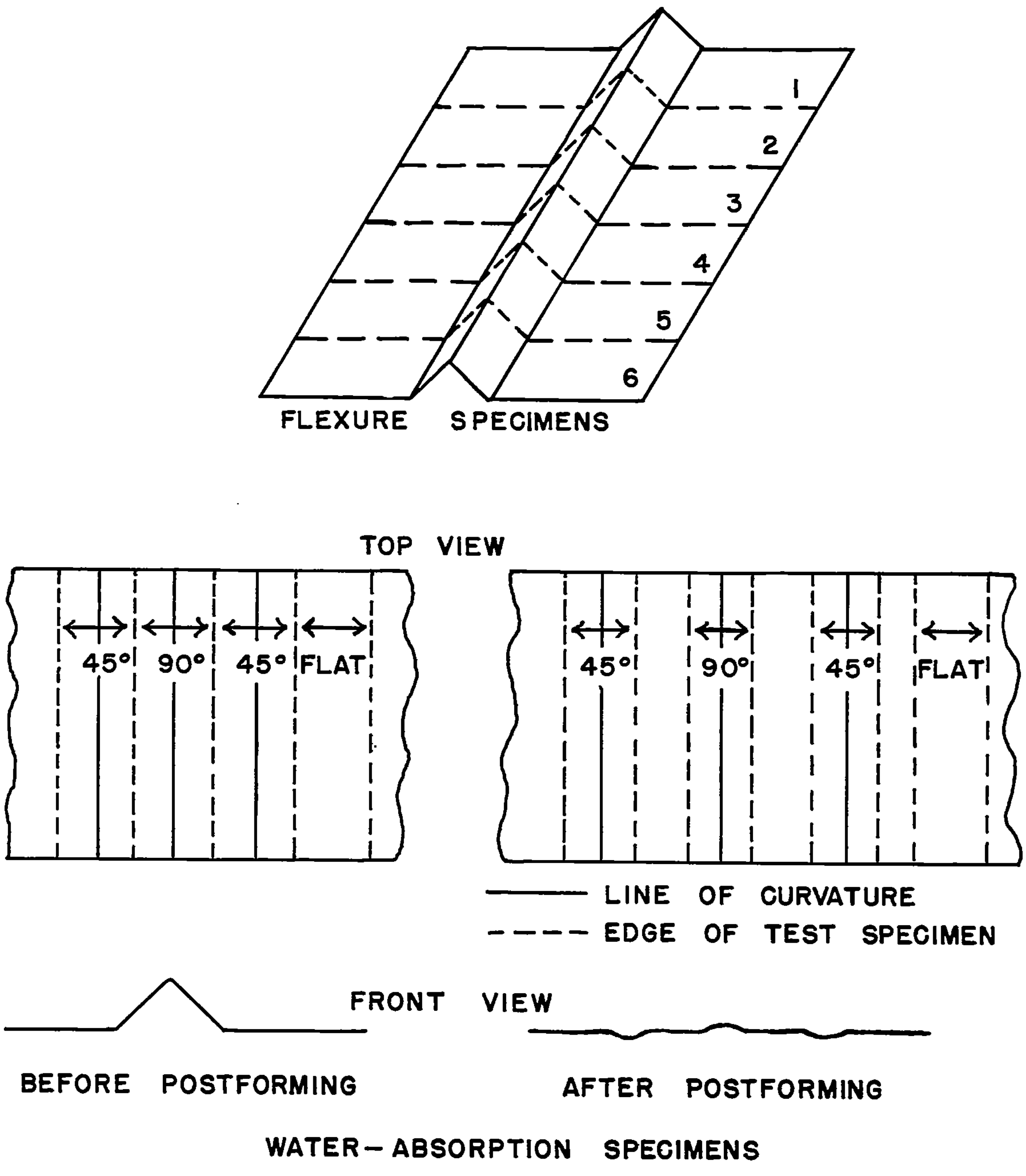
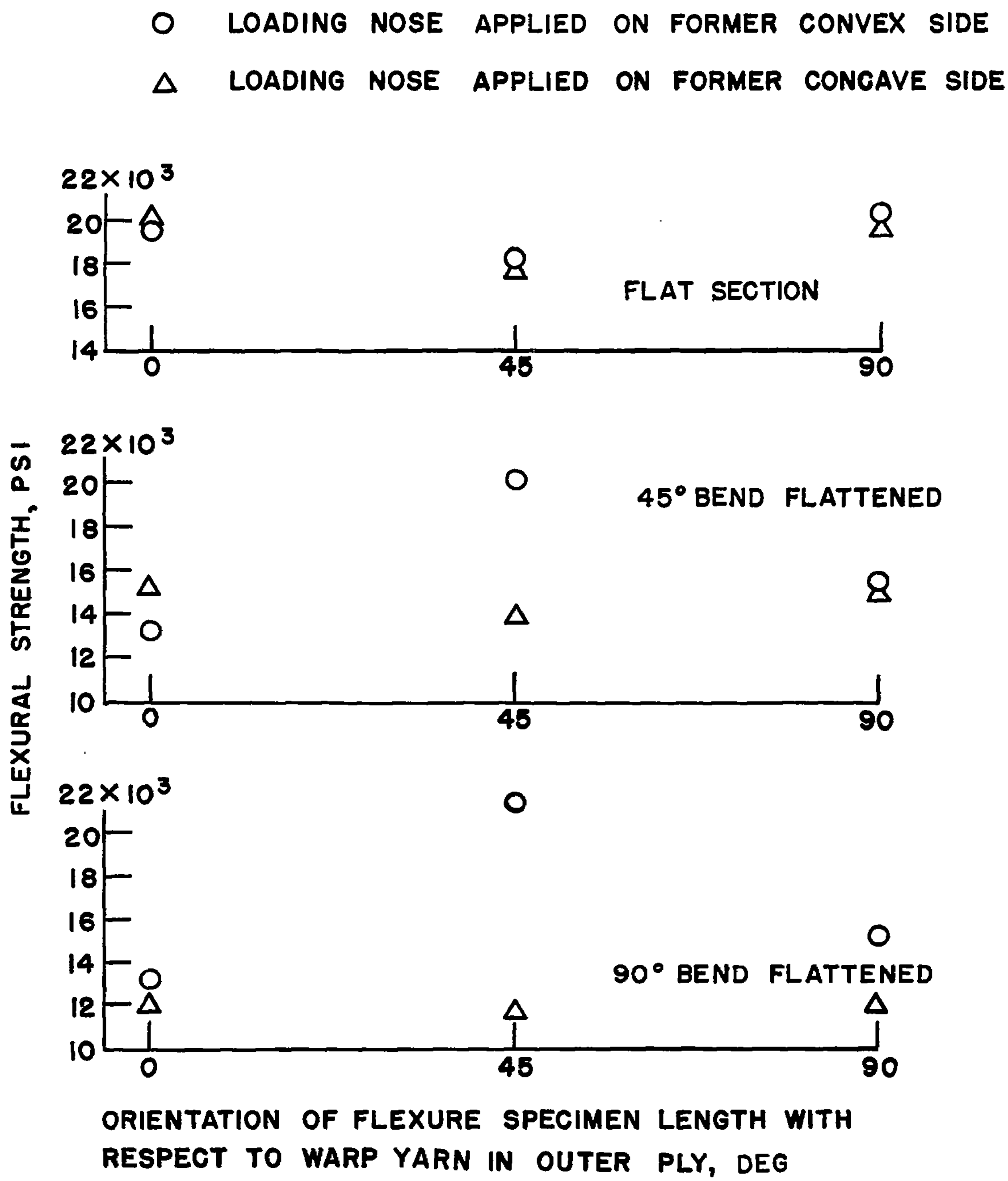
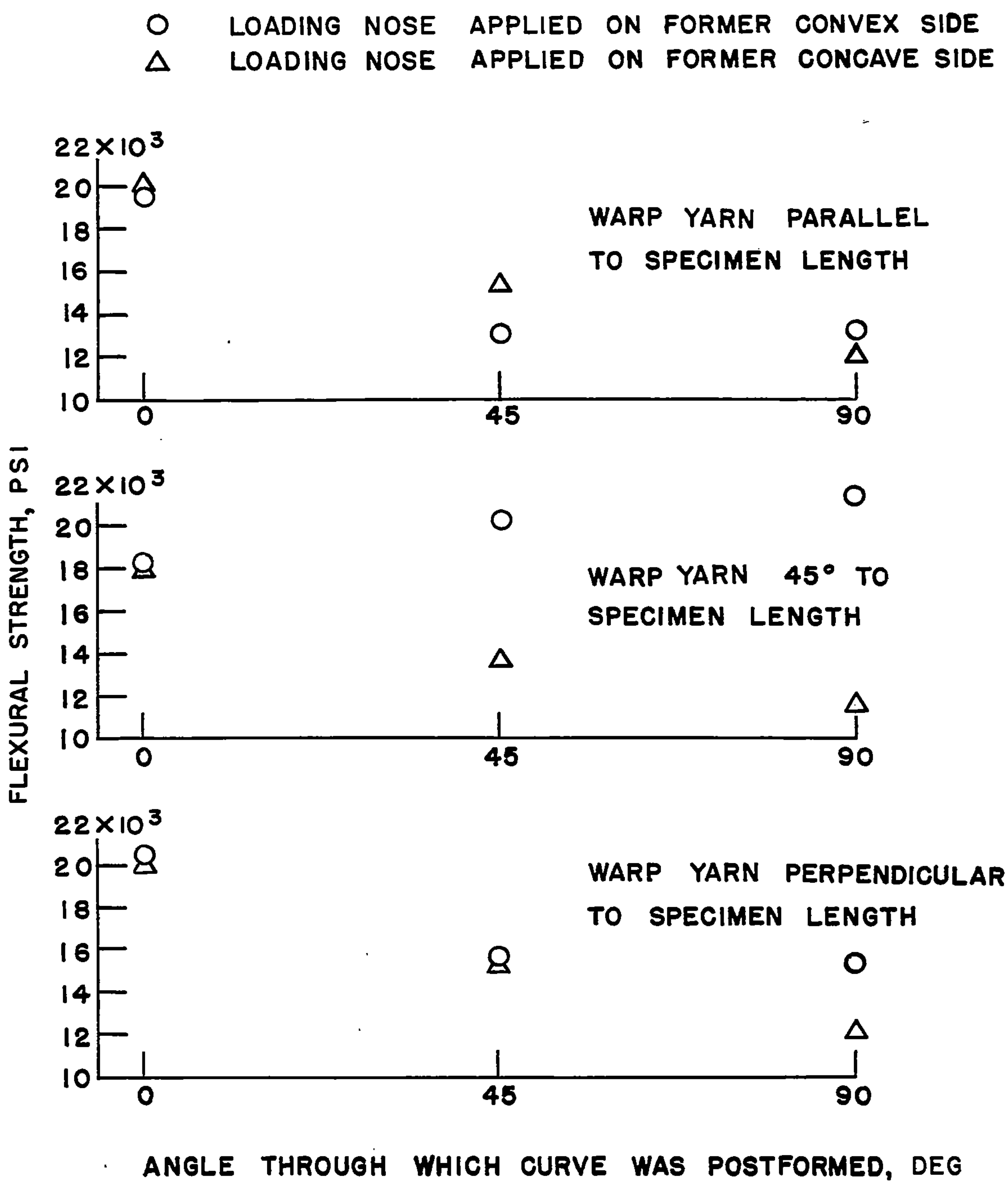


Figure 6.- Orientation of specimens from molded V-sections and flat panels postformed from V-sections, samples MC1 and MC2 and samples PC1 and PC2, respectively.



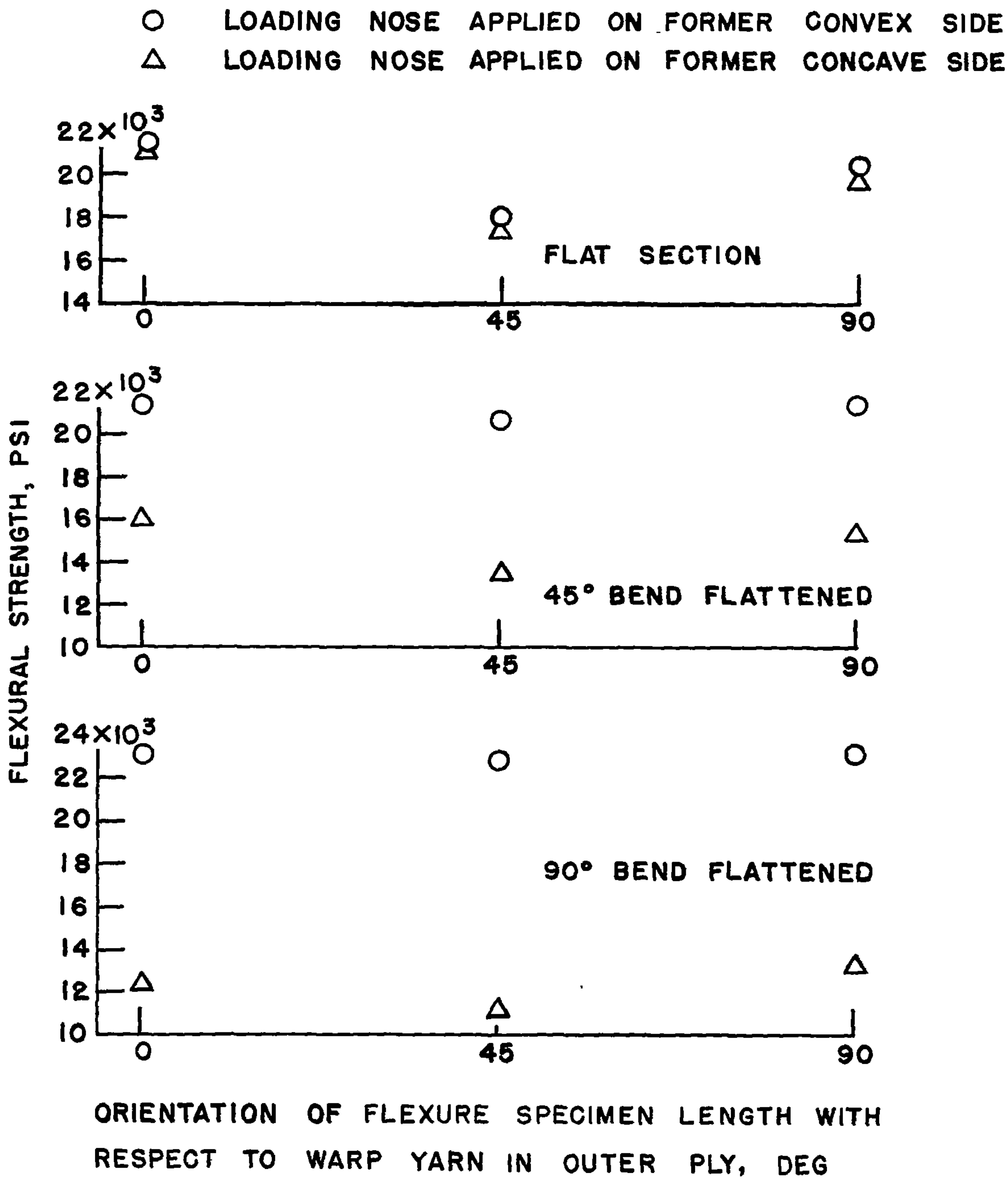
(a) Strength against direction of warp yarn in specimens.

Figure 7.- Variation of flexural strength of postformed curved sections, sample PC1.



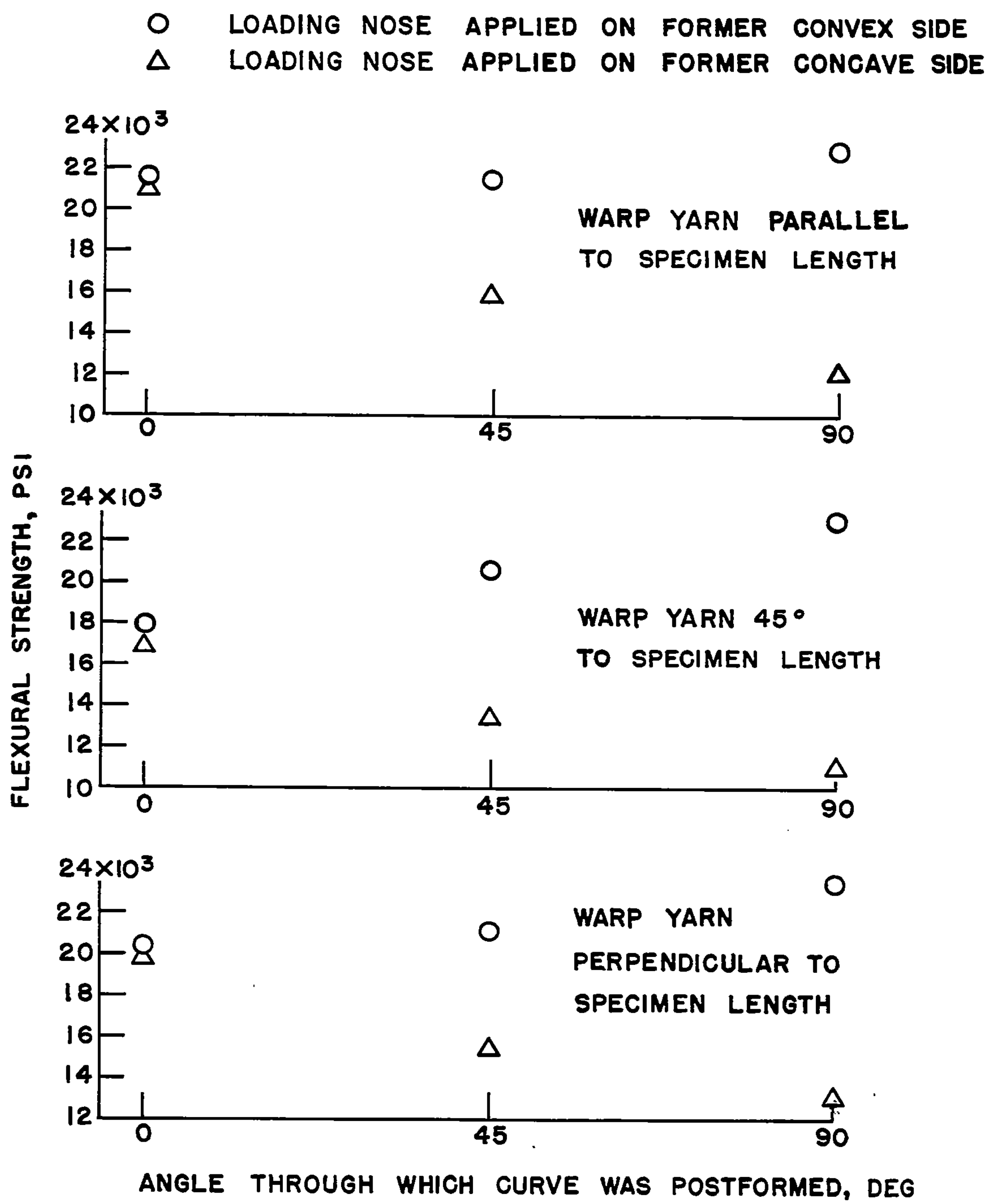
(b) Strength against postforming bending angle.

Figure 7.- Concluded.



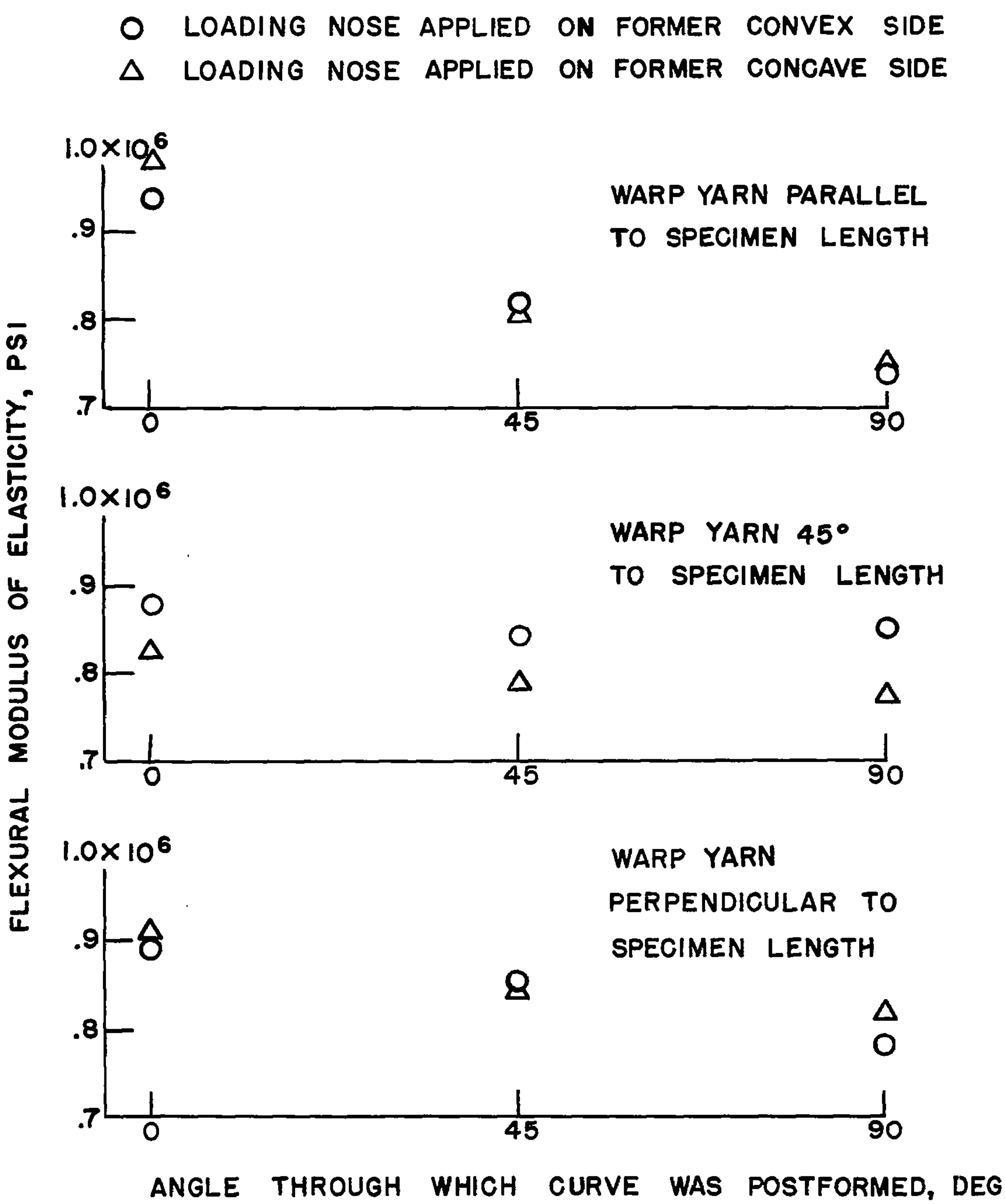
(a) Strength against direction of warp yarn in specimens.

Figure 8.- Variation of flexural strength of postformed curved sections, sample PC2.



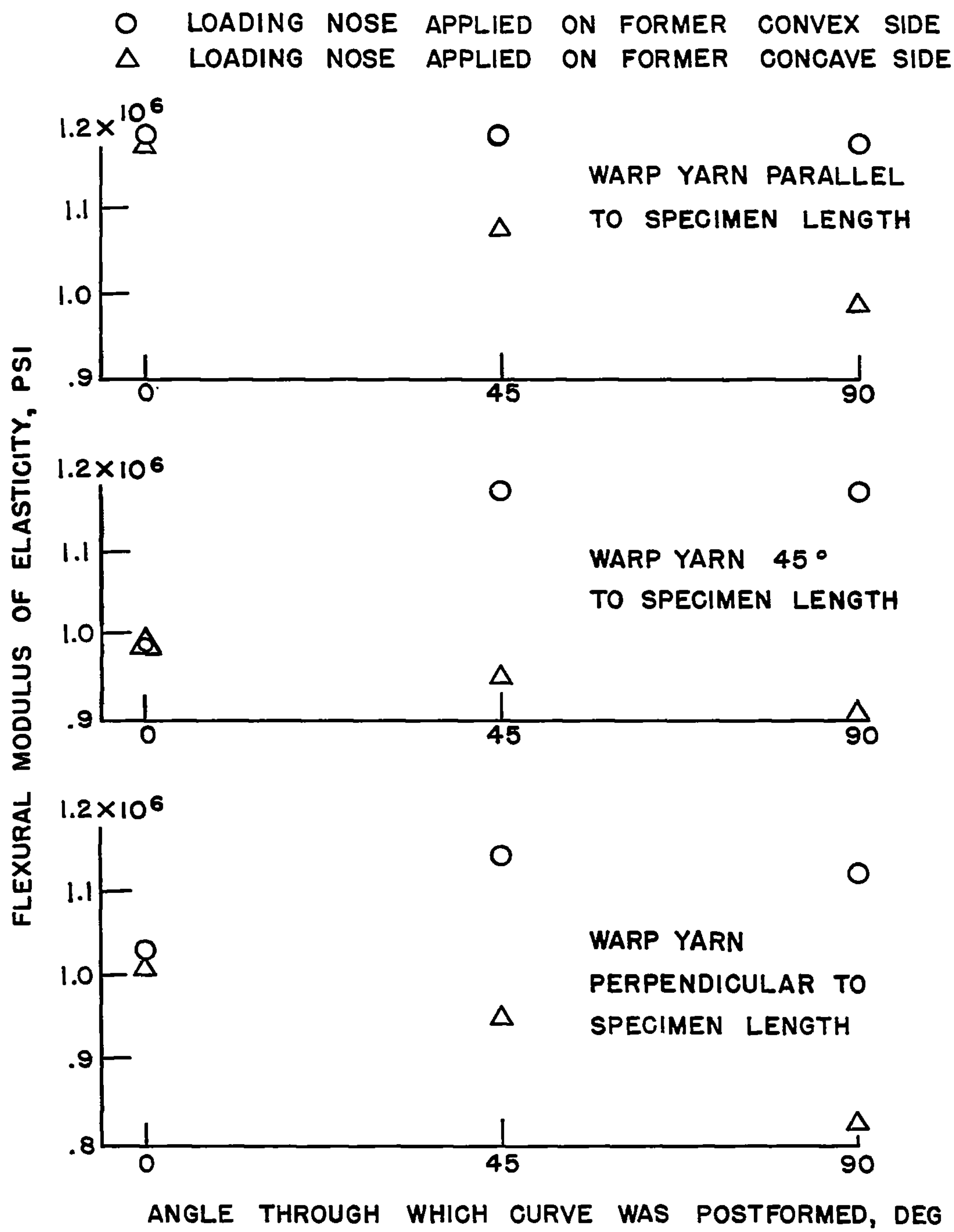
(b) Strength against postforming bending angle.

Figure 8.- Concluded.



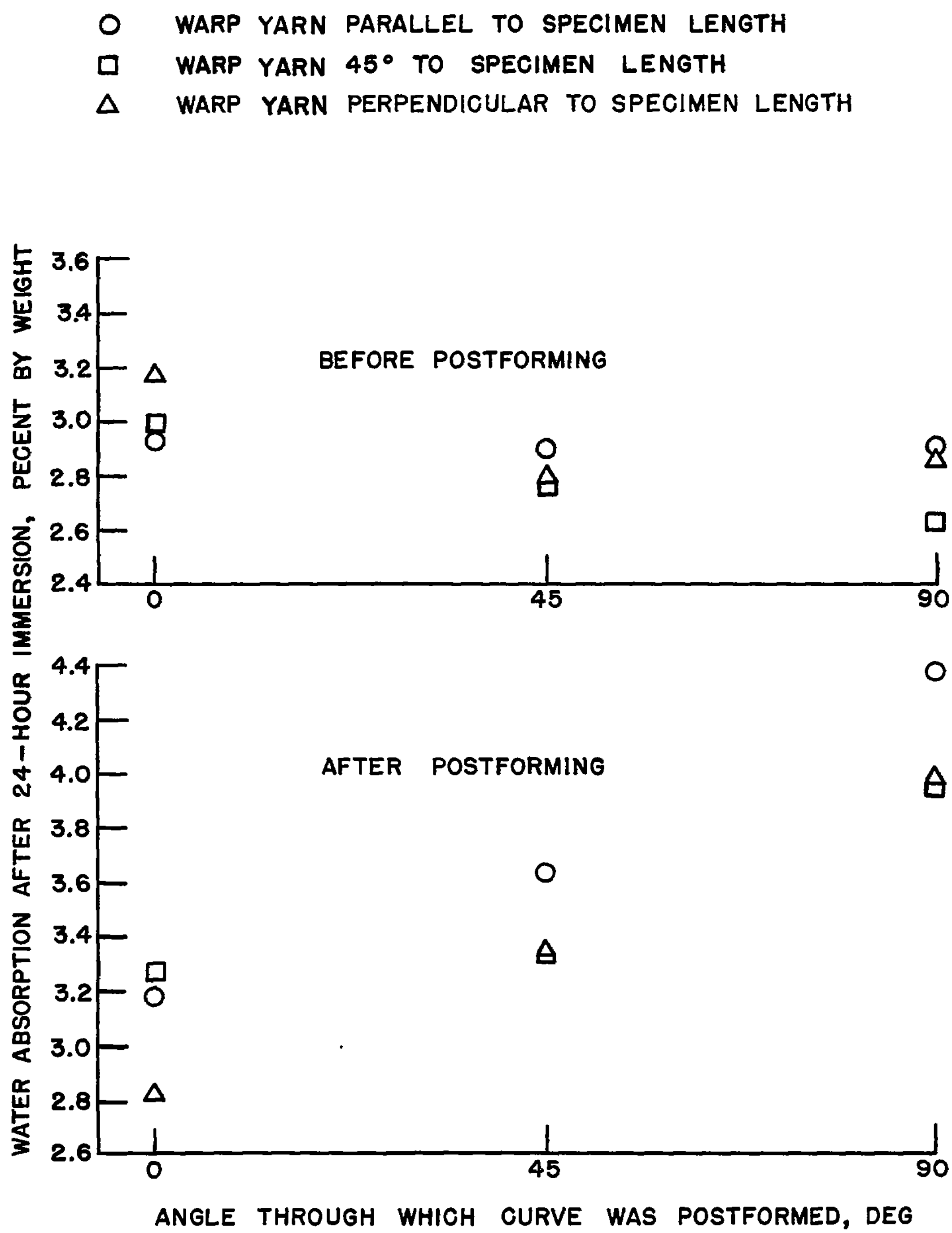
(a) Sample PC1.

Figure 9.- Variation of flexural modulus of elasticity of postformed curved sections with postforming bending angle.



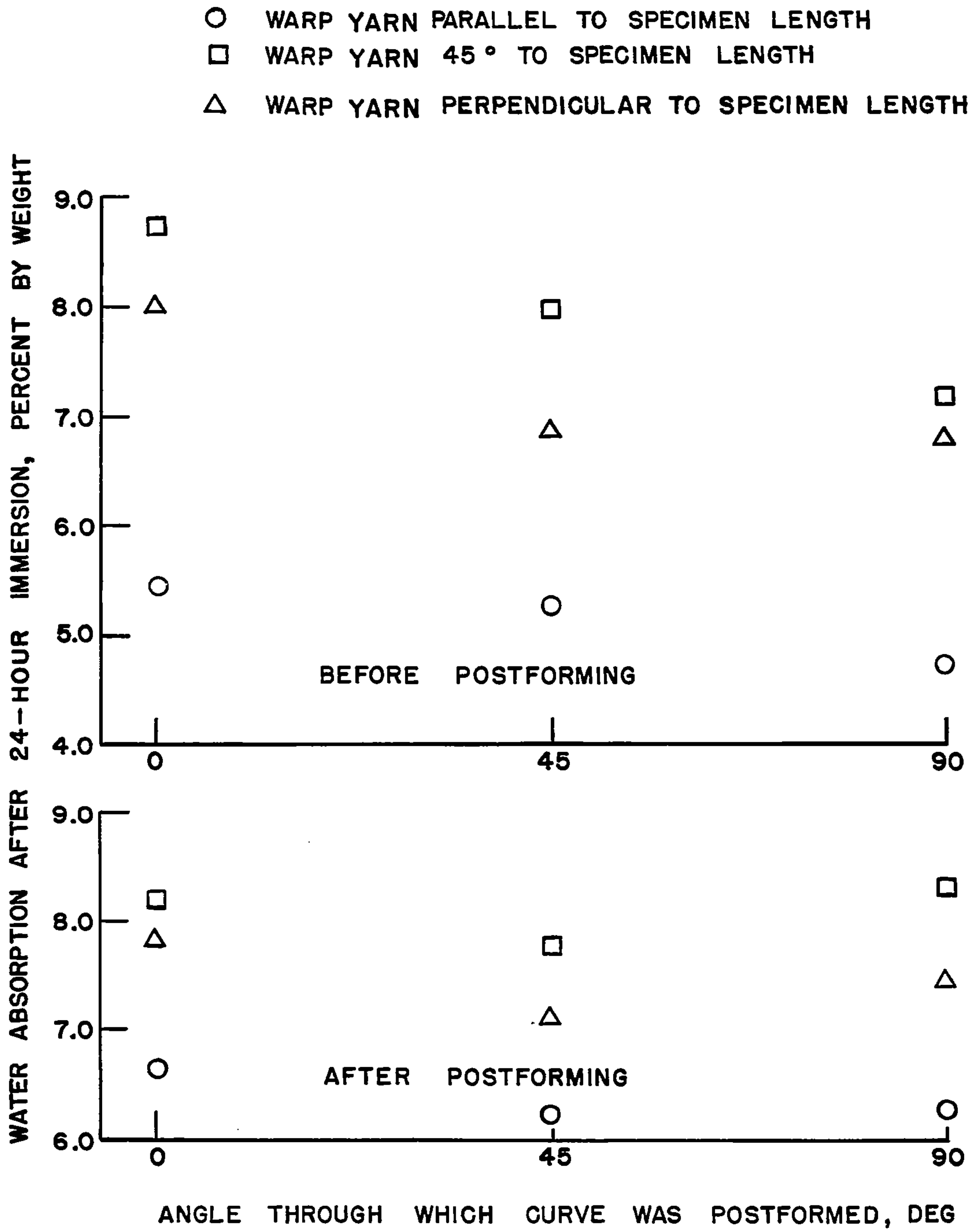
(b) Sample PC2.

Figure 9.- Concluded.



(a) Sample PC1.

Figure 10.- Effect of postforming on water absorption of molded V-sections.



(b) Sample PC2.

Figure 10.- Concluded.

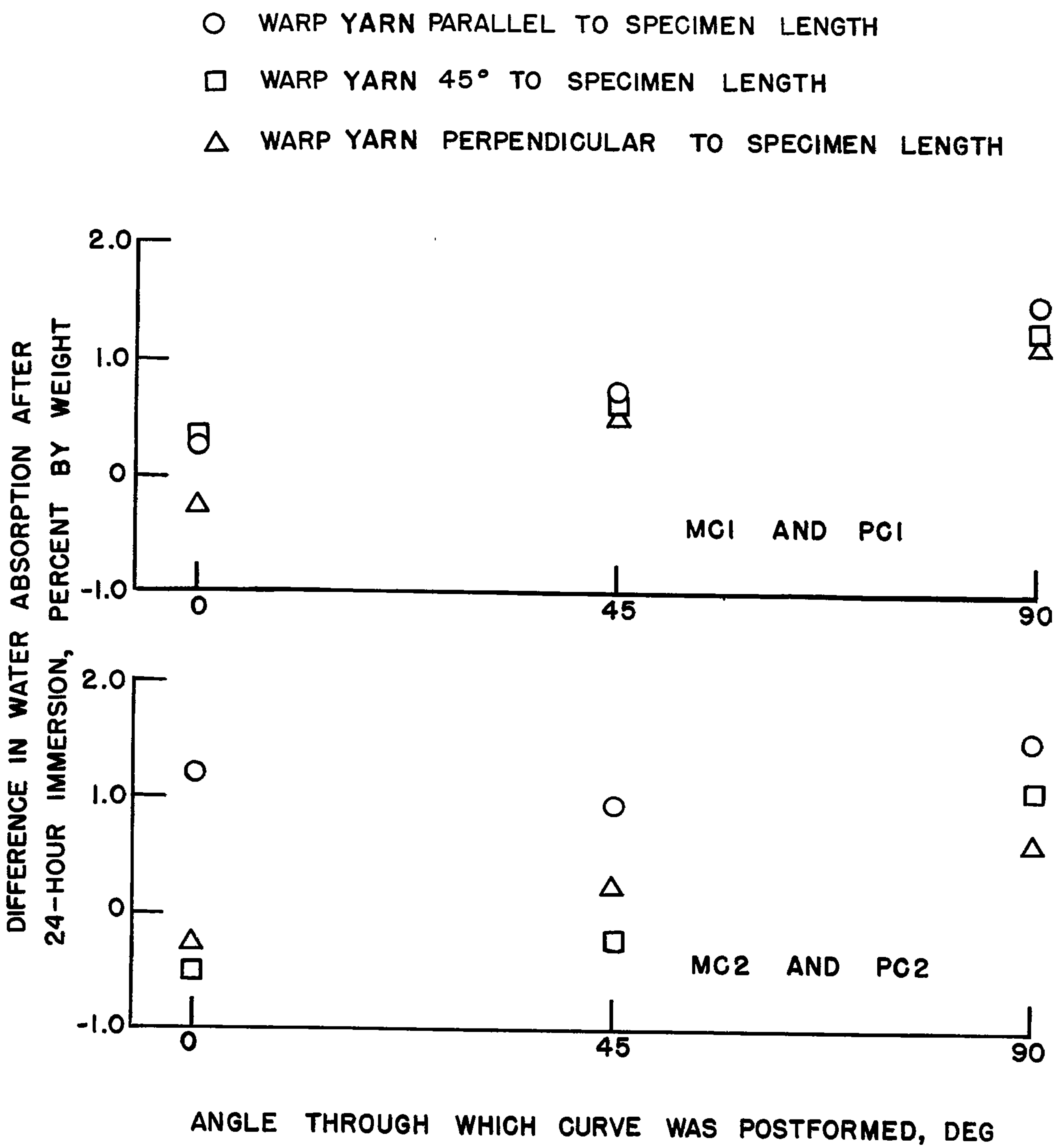


Figure 11.- Difference in water absorption of molded V-sections before and after postforming.

NACA - Langley Field, Va.